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THE PLANET MARS

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(A lecture given to the British Interplanetary Society in London, on December 11, 1954)

SUMMARY

Following the first flights into space and the conquest of the Moon, it is reasonable to assume that the next bodies to be reached will be Mars and Venus. Of the two, Mars is probably the more inviting. It is not without water; there is an atmosphere, there is probably plant life, and the temperature is not impossibly low. Although recent investigations have given us much information, there is still a great deal that we do not know; for instance, we have not yet found out the exact nature of the so-called "Violet Layer" which normally protects the surface of the planet from the short-wave solar radiation, and we are still uncertain as to the exact nature of the famous "canals" though it is now considered that the existence of higher forms of life upon Mars is extremely unlikely. Researches carried out during the recent opposition of the planet are discussed, with an outline of the observing programme to be followed at the very close approach of September, 1956.

Introduction

Just over twenty-one years ago, a number of enthusiastic amateur and professional scientists formed themselves into the British Interplanetary Society. In those dim and far-off days, before the enlightened era of the atom bomb, rocket experimenters were regarded as frankly funny, and anybody suspected of having even a remote connection with the BIS was considered an automatic candidate for a straight-waistcoat and a padded cell. At the present time, the situation is rather different. Nobody in this Society, at least, has any hope of building a personal spaceship—quite apart from the restrictions of the Explosives Act of 1875!—but we have at least reached the stage where interplanetary flight has become more than a possibility. Some of those present to-night may well see the first spaceships take off.

That being so, the next question is: "Where shall we go?" The obvious answer is: "The Moon, because it is so near." With this, I am in entire agreement. Because it is the Earth's companion in space, a mere quarter of a million miles away, the Moon will undoubtedly be the first world to be reached. On the other hand, the lunar conditions are likely to be uncomfortable, to put it mildly, and we are likely to regard the Moon as a mere stepping-stone to the more distant but even more intriguing planets, Venus and Mars.

About Venus I can say nothing to-night, partly because it is outside the theme of my talk and partly because we know practically nothing about it.

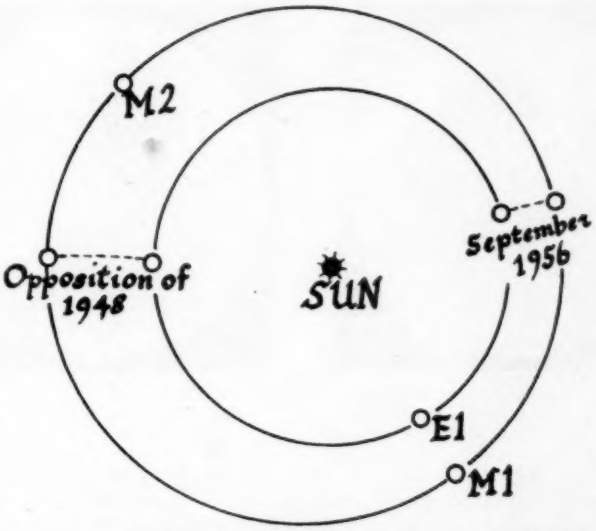
But Mars is a very different proposition. The books written about the Red Planet would fill a fair-sized library, and during the past three and a half centuries we have gathered a remarkable amount of information about it; I would like to summarize this information as clearly and concisely as I can, coupled with some information of recent investigations carried out during the close approach of 1954.

Mars must have been known from the dawn of human history; even the sub-men, the Cro-Magnards of 25,000 years ago, must have noticed the brilliant red star-like object that glows balefully down from the heavens like a drop of blood. When the time came for the "wandering stars" or planets to be named, it was natural to select for this red orb the name of the God of War; and this is, I imagine, one reason why most story-tellers are anxious to make their hypothetical "Martians" grotesque monsters whose one idea is to freeze us, fry us with heat-rays, annihilate us, or behave in some similarly unfriendly manner.

The ancient peoples believed the Earth to be the centre of the universe. This was natural enough; a few misguided people still think so—up to the beginning of the war, there was actually a flourishing Flat Earth Society in London, whose disciples followed the ideas of a Mr. Voliva, who believed that the precise shape was that of a gramophone record, with the North Pole in the middle and a wall of ice all round. (When questioned about the South Pole, he replied firmly: "There *isn't* any South Pole.") But in 1546 a Polish canon, Copernicus, published a book which showed pretty conclusively that the centre of the Solar System was the Sun, not the Earth. Copernicus followed the old idea of perfectly circular paths or "orbits," as the circle was supposed to be the perfect form, but the trouble about his theory was that it could not be proved —because the movements of the planets were not known with sufficient accuracy. This was altered during the following fifty years, mainly because of the labours of a Danish nobleman named Tycho Brahe. Tycho's main observations were, as a matter of fact, devoted to Mars; and using these measured positions, the German mathematician Kepler was able to prove that the Red Planet does indeed move round the Sun—not in a perfect circle, but in a slightly eccentric ellipse.

I do not propose to say much about the movements of Mars to-night. Still, a few facts and figures must be given. The Earth is 93 million miles from the Sun; Mars is more distant, revolving at an average distance of rather over 141 million miles. Owing to the eccentricity of the orbit, this average distance is reduced to 129 million miles when Mars is closest to the sun, at "perihelion," and increased to 154 million when Mars is most remote, at "aphelion." Naturally, the Martian year is longer than ours—partly because the orbit is longer, and partly because Mars is moving more slowly (about 15 miles a second, as against our 18½). According to the terrestrial calendar, I am thirty-one; by Martian reckoning, I would still be in my teens. Unfortunately there is no prospect of journeying to Mars for the purposes of rejuvenation.

When the Sun, the Earth and Mars are in a straight line, with the Earth in the middle, Mars appears opposite to the Sun in the sky—and is then said to be at "opposition." This was the case in July, 1954. But oppositions, when Mars is naturally very well placed for observation, do not occur every

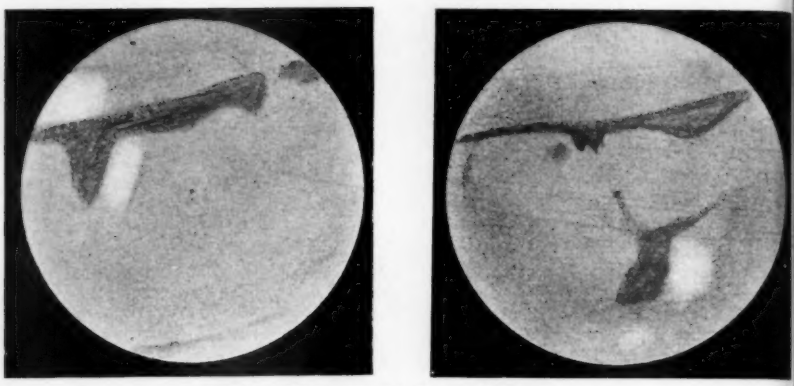


Favourable and unfavourable oppositions of Mars. The eccentricity of Mars' orbit is slightly exaggerated in the diagram. E1 and M1 represent the positions of Earth and Mars at the opposition of 1954.

year. The diagram (Fig. 1) will make this clear. In July, 1954, Mars was at M1 and the Earth at E1. A year later—in July, 1955—the Earth will have completed one circuit of the Sun, and will have returned to E1; but Mars, moving more slowly in a larger orbit, will not have arrived back at M1. It will only have reached M2, and will be on the far side of the Sun, very badly situated for observation. Before the three bodies are lined up again, the Earth has to catch Mars up; and this will not be accomplished until September, 1956. In other words, oppositions of Mars only occur at intervals of slightly over two years.

One further fact can be gathered from the diagram. The Earth's orbit is pretty well circular, but that of Mars is eccentric. In 1954, opposition occurred with Mars nearly at perihelion, and the minimum distance between the two worlds was a mere 40 million miles; in 1956, Mars will be almost exactly at perihelion, and the distance will be reduced to 35 million miles, a state of affairs that last occurred in 1924. The 1948 opposition, however, occurred with Mars at aphelion, and the minimum distance was never less than 63 million miles. Clearly, oppositions are not equally favourable; and we must make the best possible use of our opportunities. That is why planetary astronomers are becoming so excited about the observations to be carried out in 1956.

Mars, like all the planets, shines only by reflected sunlight. Near opposition, the sunlit and thus shining face is turned wholly towards us, and the disk appears circular; but when Mars is some way from opposition, a little of the dark side is



Mars, 1952. Patrick Moore, F.R.A.S.
Left: April 17. 1 hr. 14 min. 8½-in. Reflector × 300. λ 320°·1.
Right: May 17. 22 hr. 45 min. 15¼-in. Reflector × 400. λ 011°·6.

turned in our direction, and the planet appears "gibbous," the shape of the Moon a day or two either side of Full. This effect is quite striking, and was in fact first discovered by Galileo with his primitive telescope.

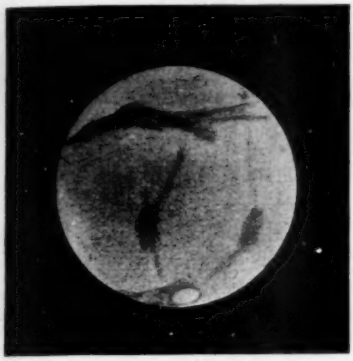
In other respects, Mars is much like the Earth. The tilt of the axis is similar, so that the seasons also are similar, though much longer; and the length of the "day" is 24 hours, 37 minutes, only about half an hour longer than our own. In some ways, then, the first Martian explorers will not feel particularly strange.

Mars as a Planet

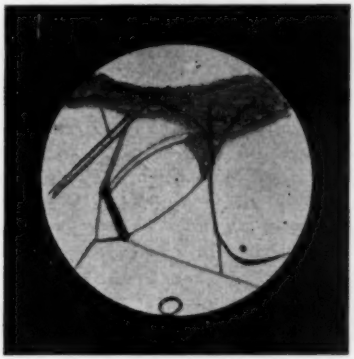
Let us now leave the movement of Mars to the mathematicians, and turn to the Red World considered as a planet. At once we are struck by the marked resemblance to the Earth. Like our own globe, Mars is a solid body, with a certain amount of moisture; there is an atmosphere, and there is (probably) plant life. The main difference is that Mars is much the smaller of the two. Its diameter is only 4,200 miles, compared with our 7,926; this makes the volume 15 per cent. and the mass 11 per cent., reckoning the Earth as unity. We can in fact regard Mars as intermediate in size between the Earth and the Moon.

Naturally, we are still rather in the dark as to the internal constitution of the planet. Probably it is made up in much the same way as is the Earth, with a central core of nickel-iron and the covering layers as postulated by geologists. As the mean density of Mars is less than that of the Earth, it is reasonable to assume that the core is smaller; and if we are right in supposing that it is this core which is mainly responsible for terrestrial magnetism, we shall probably find that the magnetic field of Mars is rather weak. Needless to say, this is only guesswork, and we shall not find out for certain until we arrive.

The most important consequence of this lack of mass is that Mars has lost a good deal of its atmosphere. According to modern ideas, the Earth once had



Mars, April 28, 1952.
12½-in. Reflector × 400.



Mars. Lowell-type canals.

a dense air, which was lost in the far-off times when our planet was fiercely hot; a secondary atmosphere was then developed by volcanic action, and this secondary atmosphere has (fortunately for us) been retained. The past history of Mars is probably similar, but not only the primary but also much of the secondary atmosphere has wasted away by now. The escape velocity for the Earth is 7 miles a second, as everyone knows; for Mars, it is only 3·1 miles a second. I shall return to this question later. Meanwhile, it will suffice to say that a man who weighs 14 stone at home will weigh only 5½ stone on Mars. As his muscles will naturally be unaffected, he will seem to have acquired the strength of a Hercules—or more appropriately, perhaps, that of an Antæus!

Mars through the Telescope

With his feeble telescope, magnifying only 30 times, Galileo was naturally unable to see much on Mars; he did well even to detect the phase. The first proper drawing was made by Huygens, a Dutch scientist, in 1659, and shows one of the famous dark markings, the Syrtis Major, in perfectly recognizable form. Huygens realized at once, that unlike Venus, Mars presented a solid surface that could be studied; and by following the drift of the surface markings, he worked out a rotation period of something like 24 hours. At about the same time, drawings were made by an Englishman, Hooke; in Italy, Cassini discovered the icy polar caps.

Little further work was done for some time, but in 1779 a German amateur, Schröter, began to make a series of observations of the Moon and planets that inaugurated the modern era of the astronomy of the Solar System. It would be out of place here to do more than mention a few of Schröter's successors—Beer and Mädler, who drew the first reliable map in 1840; Pickering, Lowell, Schiaparelli and Green in the late nineteenth and early twentieth century; and in our own times men like Antoniadi of Greece, Barker of Great Britain, and Lyot and Dollfus of France.

I want to dwell for a moment on the work carried out at the two great French observatories, Meudon and the Pic du Midi. Twenty years ago, the leading planetary worker was Antoniadi, Greek by birth but resident in France, who used the 33-inch telescope at the Observatory of Meudon for his observations of Mars. I have used this great instrument myself to make a series of lunar observations, and there is no doubt in my mind that it must be among the best telescopes in the world. There are only two larger refractors, both in America. More recently, Dollfus has been at work with the 24-inch at the Pic du Midi, situated almost 10,000 feet up in the Pyrenees between France and Spain; and it must, I think, be admitted that his results are more reliable than those of anyone else, partly because of his supreme excellence as an observer and partly because of the fact that he is working under very favourable conditions of seeing.

The ordinary small telescope will show Mars as an orange disk, spotted here and there with darker areas that show a trace of blue-green, and crowned by the gleaming polar caps. Some people are under the impression that even a small instrument will reveal startling details, including the famous canals, but this is an obvious misapprehension; Mars is a small world, and never comes closer than 35 million miles of us, so that even with great telescopes we cannot study its surface features in any detail. It is rather humbling to realize that even the 200-inch Palomar reflector will give a view of Mars no better than that of the Moon through ordinary binoculars.

The Polar Caps

Let us now start our review of the chief features of Mars, and it is fitting to begin with the gleaming ice-caps which cover the poles of the Red Planet.

These caps were first seen by Cassini in 1666, the year of the Fire of London. He described the polar zones as being covered with bright, whitish deposit that looked remarkably like snow; in fact, he thought that it actually was snow. Whichever pole happened to be turned towards the Earth showed this covering, and the resemblance between the Martian frigid zones and those of our own world was obviously more than merely superficial. Seen from outer space the Earth would show similar polar caps.

A century and a quarter after Cassini, interesting observations were made by William Herschel, the discoverer of the planet Uranus. Herschel was the best observer of his time, as well as the best telescope-maker, and not unnaturally he saw much detail on Mars; moreover, he realized that the polar caps melted steadily during the Martian spring and early summer, reaching their minimum size in late summer. He agreed, therefore, that they were made of ice and snow.

There are some people who delight in rejecting a plausible explanation, and searching for a wholly unlikely one. It was thus over a century more before the simple nature of the Martian caps was admitted. Even in 1903, A. C. Ranyard and Dr. Johnstone Stoney put forward the idea that the caps were not snowy at all, but made up of solid carbon dioxide—"dry ice." They did not explain how it got there, but that apparently did not matter, and the carbon dioxide caps kept on appearing in astronomical literature until 1948, when spectroscopic investigations by Kuiper, at the McDonald Observatory

in Texas, proved once and for all that the caps are fundamentally the same in nature as the snowy mantles covering our own poles.

Yet there is a difference. The caps of the Earth are extremely thick; North Greenland and Antarctica, for example, are covered with an icy layer of great depth. The Martian caps melt so quickly when the warmer weather comes that they must be extremely thin. Their depth cannot, in fact, be more than a few inches, so that the total amount of water locked up in them would not fill a lake the depth of Windermere and the size of Wales.

As with the Earth, the summer in the northern hemisphere of Mars occurs when the planet is farthest from the Sun. So far as we are concerned, the difference in heat received is not great, as our orbit is practically circular; but Mars' orbit is eccentric, and thus the southern hemisphere is the hemisphere of extremes. The summers, which occur near perihelion, are short and comparatively hot; the winters long and bitter. At its greatest extent, the southern cap may cover an area of over 4 million square miles; yet later in the same Martian year it shrinks to a tiny patch, and in 1894 it actually disappeared completely for a short while. This state of affairs is highly unterrestrial. Scott and Amundsen could never hope to find Antarctica deprived of its characteristic snowy mantle. The northern cap, which experiences less extreme temperatures, does not vary so much; but even so it can cover a tremendous area in the depths of the northern winter, while at minimum it cannot be seen without a telescope of some power.

As a cap melts in the Martian spring, it is seen to be bounded by a darkish band. This band can be seen without much difficulty by any observer using a powerful instrument, and it is definitely not an optical effect due to sheer contrast, as some astronomers have believed. It is not particularly mysterious. As the cap melts, moisture is released; this dampens the ground—and damp ground shows up as darker than dry ground. As the cap continues to recede, the damp areas dry out, and so the band appears to shrink with the cap.

Lowell and others have considered that there might even be a short-lived polar sea, but owing to the extreme thinness of the caps this appears unlikely—there is simply not enough water. Occasional pools are as much as we could ever expect to find, and even these are dubious.

It may, in fact, be misleading to say that the Martian polar caps "melt" at all. Under some conditions of temperature and pressure, it is possible for a solid substance to "sublime," e.g. pass directly from the solid into the gaseous state without ever becoming liquid at all. Terrestrial snow cannot behave like this, but on Mars the atmospheric pressure and the temperature are much lower, so that a certain amount of sublimation must occur. It has even been suggested that sublimation is the main mechanism in the shrinking of the polar caps, though on the whole this view is rather difficult to maintain.

One of the most interesting points about the shrinking of the polar caps is that it is not entirely regular. The boundary becomes broken, and dark rifts appear in the cap itself; bright snowy areas are left behind the general decrease, to vanish some time later. These rifts and isolated patches always appear in the same places at the same periods in the polar cycle, so that they are definitely due to surface peculiarities.

I do not imagine that there can be much doubt as to their nature. On Earth, snow persists longest on high ground. Presumably the same is true for Mars, so that the snow-covered patches must be elevated plateaux, perhaps several thousands of feet in height. The rifts are probably valleys.

As the Martian autumn draws on, and winter approaches, the cap becomes hidden by a whitish overlying haze which can sometimes become prominent enough to be mistaken for the cap itself. The winter growth of the polar snows is hidden from us, partly because of the haze and partly because Mars has drawn too far away from us to be properly observed. By the time that the Red World swings near once more, the haze has cleared, leaving the cap again bright, regular and extensive.

But the vital importance of the polar caps is that they are bound up with the whole seasonal cycle of Mars. As a cap melts, and moisture is released, the dark areas near the pole darken and harden, as though waking to life; and a "wave of darkening" passes from pole to equator, which seems to indicate the existence of something that lives and grows. This brings us at once to the problems set by the dark areas of Mars.

The Dark Areas

Up to about sixty years ago, it was generally believed that the dark areas of the planet were seas. Nowadays, we know better. Mars is desperately short of liquid, and there are no sheets of open water anywhere on the planet. There are any number of proofs of this, but two will suffice; the atmosphere suffers from an almost total lack of water vapour, and the dark areas contain much fine detail visible with a powerful telescope.

However, the areas are more or less permanent in outline. They have been accurately mapped; e.g. a chart was drawn in 1937 by Robert Barker, who is one of the most eminent of modern observers of the planet. It shows the V-shaped area known as the Syrtis Major, the same feature as was shown by Huygens in his rough sketch of 1659. Other important areas are the Mare Acidalium, the Mare Erythræum and the Mare Sirenum, while later on I shall have occasion to refer to that curious little feature known by the poetic name of the Solis Lacus, or Lake of the Sun.

In 1877—a red-letter year in Martian annals—Liais, a French astronomer who did most of his work in Brazil, suggested that the dark areas were not seas at all, but tracts of vegetation. Like the snow theory of the polar caps, this was eminently reasonable; like the snow theory, it met with a curious amount of opposition that is not quite dead even now. The key to the whole problem is, of course, the seasonal "wave of darkening" which takes place as the polar cap melts. This wave is not regular; some dark areas are more responsive than others, and one comparatively small patch, the Trivium Charontis, always appears dark greenish, so that it is probably a depressed area several thousands of feet below the level of the surrounding surface.

Moreover, certain alterations take place in the shapes of the dark areas during the seasonal cycle. Superimposed on them are irregular and unpredictable changes; the little Solis Lacus, for example, is notorious in this respect —it can change its shape entirely, as happened in 1926 and again in 1939,

remaining unfamiliar for some years before returning to its original appearance. This gives the impression of the retreat or spread of vegetation with respect to the adjacent desert areas.

Probably the strongest argument in favour of the vegetation theory is that put forward by Dr. Ernst J. Öpik, an eminent Estonian astronomer now resident in Ireland. Dr. Öpik points out that as winds on Mars are quite strong, a great deal of dust must be blown from the ochre deserts on to the greenish areas (we can even see dust-storms, as I shall show later). If the dark areas were not due to something that grows, and can thus push the dust aside, they would be completely covered in a few hundred years at the most, and the whole planet would assume a monotonous, uniform hue. Needless to say, this does not happen.

If we are wrong, and the dark areas are not due to vegetation—what are they?

Svante Arrhenius, the Swedish scientist who won a Nobel Prize in chemistry, supposed them to be composed of hygroscopic salts, e.g. salts which absorbed moisture, darkening in the process. Arrhenius' theory has never met with much enthusiasm, and recent work on the subject by Dr. Kuiper, at McDonald Observatory, seems to show that it is definitely untenable—there is simply not enough moisture on Mars for any such process to happen. Remember, the Martian plants, if they exist, must be able to manage on a vanishingly small supply of moisture, much of which must be carried by the winds and not conveyed to them in liquid form at all.

Very recently, a new theory has been put forward by Dr. Dean B. McLaughlin, of the University of Michigan. Dr. McLaughlin is of the opinion that the dark areas are nothing more nor less than ash ejected from Martian volcanoes. There seem to me to be so many objections to this idea that it is pointless to chronicle them all; it will be enough to say that no volcanic ash deposit could behave in the way that a Martian dark area does when moisture reaches it from the polar cap. Moreover, Mars is an ageing world, and extensive vulcanism is highly unlikely.

All things considered, we come back to Liais' original idea—that of tracts of vegetation. It is a cheering thought, as it does at least show us that Mars is a living and not a dead world. As to the precise nature of this vegetation, we can only speculate, and I shall return to the question later.

The Ochre Areas

Through a powerful telescope, Mars is a beautiful object. The harsh ruddiness of the War-God is tempered to warm ochre; the disk appears pleasant and friendly, streaked by its darker greenish areas of vegetation and crowned by its gleaming caps, which glitter like jewels across the millions of miles of void. Yet in reality, it is this very ochre colour which makes Mars so forbidding. The warm glow is a hollow mockery; the ruddy tracts are simply deserts, wild and chill, where not even low-type plants can manage to survive.

It was not until a century and a half ago that this was realized. Early observers thought that the prevailing red colour was due to some peculiar quality of the Martian atmosphere; others believed that the planet was covered

with orange vegetation, similar to the "red weed" in Wells' famous story of later times. But nowadays, the desert theory is so well established that few people question it.

Needless to say, the deserts are not sandy, like ours. Sand is the accumulation of soiling and igneous rock débris by running water, and running water is unknown on Mars—probably there never was much of it. A later theory suggested that the surface rocks of Mars had combined with oxygen in the atmosphere to form a layer of iron oxide—in other words, common rust. For many years, rusty deserts were considered highly probable.

Recently, alternative suggestions have been made. Dr. Lyot, the brilliant French observer who died in 1952, believed that the ochre areas were covered with volcanic ash; spectroscopic observations have led Kuiper to believe that the surface layer is made up of the brownish igneous rock known to geologists as felsite (a silicate of aluminium and potassium), while Dollfus prefers an irregular deposit of an oxygen-iron compound known as limonite, spread about in a pulverized condition. At the moment, we cannot be certain which of these ideas is correct, but we do at least know that five-eighths of all Mars is arid waste. The ochre hue is not the bloom of youth. It is the deathlike flush of extreme old age.

The Atmosphere of Mars

We now come to one of the most vital questions concerning Mars—that of its atmosphere. That Mars has a gaseous mantle, we know; as long ago as 1784, Sir William Herschel realized it, and more recently so much evidence has accumulated that nobody with any astronomical knowledge would question its validity. On the other hand, the mere existence of an atmosphere does not mean that an Earthman could breathe there. Jupiter has an atmosphere, too—an unprepossessing mixture of hydrogen, ammonia and methane, while the air of Venus appears to be made up mainly of choking, smothering carbon compounds. Is the Martian mantle any more inviting?

The small escape velocity of the planet—only a little over 3 miles a second—would seem to indicate an atmosphere of lesser density than ours; and this is borne out by direct measurements. The air of Mars proves to be thinner than that on top of Mount Everest, and the atmospheric pressure even on the surface of the Red Planet is low, in the region of 3 or 4 inches of mercury (ours is about 29). Still, things might be worse. The atmosphere is thick enough to protect the surface from a cosmical bombardment by meteorites, and it is also able to prevent the blood-boiling danger. As is well-known, the boiling-point of a liquid depends upon a combination of its heat and the pressure upon it. At a height of 63,000 feet above the Earth, our blood would boil at body temperature, and the results are best left undescribed—which is one of the reasons why we shall have to adopt very efficient space-tailoring if we are ever to leave our rocket craft when travelling in the void. These pressurized suits would also have to be worn upon the Moon, where the atmospheric pressure is negligible. But blood-boiling will not occur on Mars, and there is indeed no reason why a man should not walk about on a summer day protected by no extra clothing other than a breathing mask.

The low density of the air would by itself be enough to show that there is no question of our ever being able to walk about on Mars without oxygen equipment, but in addition to this it seems that the atmosphere is singularly useless so far as we are concerned. It is not poisonous, but that is as much as we can say. Unfortunately, the problem of determining its exact composition is a very difficult one. For once, the spectroscope is a broken reed, simply because Mars shines by reflected sunlight; the Martian spectrum is thus a mere reflection of the solar one, and the very slight modifications caused by the presence of gases in the atmosphere are largely drowned by the greater modifications caused by similar gases in our own atmosphere.

As a matter of fact, the first measures were encouraging. In 1867, Jules Janssen, who founded the Meudon Observatory (the square outside the entrance is still known as the Place Janssen), took his instruments to the top of Mount Etna, 9,800 feet above sea level, to study the spectrum of Mars without the handicap of having to look through the densest layers of our own air. He believed that he had detected appreciable amounts of water vapour, and this was confirmed by other workers such as Huggins and Vogel. Basically, Janssen's method was to compare the spectrum of Mars with that of the virtually airless Moon; he reasoned that any differences must be due to the Martian atmosphere.

Unfortunately, later work has not borne out Janssen's necessarily rough measures. In 1933 two American astronomers, Adams and Dunham, reinvestigated the problem, using the great instruments at Mount Wilson, and came to the conclusion that there was no trace at all of any water vapour, while oxygen too was pretty well absent. On the other hand, we know for certain that Mars' mantle contains at least a little water vapour—because of the presence of the snowy polar caps, which melt in the spring—and it is true that the tests are, comparatively speaking, insensitive. It is probably fair to say that the Martian air contains not more than 5 per cent. as much water vapour as ours, while for oxygen the maximum permissible figure is 15 per cent. Carbon dioxide has been definitely found, though it is not plentiful, and there is probably some argon, but in the main it seems likely that the air is made up chiefly of the harmless but inert gas nitrogen, which, incidentally, makes up 78 per cent. of our own atmosphere.

We come now to an interesting branch of the study of the Martian atmosphere—photographic investigations. As is well known, light of short wavelength ("blue" light) is not penetrative, whereas long wavelength ("red" light) is. When photographs of Mars are taken in blue light, they appear blurred and featureless, because the surface is not reached at all; all that is photographed is the top of the atmosphere, and it is certain that the atmosphere of Mars is strangely opaque to blue and violet light. This was well shown on photographs taken in 1926 by Dr. Wright. Photographs taken with red light slice through the shielding atmosphere, and record the surface details, such as the dark areas and the polar caps, with relative clarity.

On the whole, the Martian air is more obstructive to violet and blue light than it ought to be. Something blocks the rays, and this "something" is variable. There are times when blue photographs record nothing but uniform

haze; others when some of the main surface details are clearly visible. Obviously, we are dealing with a layer of material which is practically opaque to short wavelengths, but which sometimes suffers partial clearing. This layer has become known as the Violet Layer, not because it looks violet to the eye (it cannot be seen visually at all), but because it blocks out the blue and violet light. So far, its nature remains unknown. It may be nothing more than fine dust; it may be composed principally of ice crystals—we simply do not know. A rough guess places its height at 8 miles above the Martian surface.

We know that while ultra-violet light is beneficial to life in small doses (every modern hospital has ultra-violet lamps), greater quantities of it are harmful. When the Violet Layer clears, therefore, and the vegetation below is exposed to the full blast of the solar ultra-violet barrage, the plants must be expected to suffer; and this has been seen to happen. During a great clearing of the Layer in 1941, which persisted for over a week, the development of the dark areas was halted until conditions became normal once more; obviously, the vegetation was harmed by the short-wave radiations emitted by the Sun, from which they were usually screened. This is an extra proof that the dark areas are due to something which grows.

As we all know, Mars was unusually close in 1954. From Britain, it was not well seen, because it was so low in the sky; but observations made from more southerly stations have been most illuminating. We are not likely to forget the freak weather of last summer. Mars, too, was having unusual weather. The dark areas were much bluer and more pronounced than usual; and another great clearing of the Violet Layer took place, with the usual results. We also had abnormal weather in 1939 and in 1941, and it is just possible that there is some link between terrestrial and Martian atmospheric conditions—in which case the answer is to be found in the Sun itself. Of course, this is only conjecture at the present time. We have not nearly enough evidence to be sure.

As long ago as 1808, a French astronomer named Honoré Flaugergues suggested that as our atmosphere is subject to clouds, the Martian air might have clouds of its own. In a way, Flaugergues was right. There are clouds over Mars; they have been seen by every serious observer—I have seen them myself on many occasions; in fact, they are far from uncommon. On the other hand, they are not in the least like the thunderous, towering rainclouds so common over Britain. They cannot be composed of aqueous vapour at all. And it never rains on Mars.

The clouds may be divided broadly into three types. First, there are the high-level "blue" clouds, so called because they are best seen in light of short wavelength, lying perhaps 50 miles above Mars and probably composed of material similar to that which makes up the Violet Layer—whatever that may be. Dollfus regards them more as "hazes" than as true clouds. Then there are the "white" clouds, at altitudes of between 4 and 15 miles, which can at times be very striking (some unwary observers have been led to believe that Mars has developed an extra polar cap!), and can obscure surface details below them. On one occasion, in May, 1920, even the conspicuous Syrtis Major was almost completely hidden for a while. And lastly there are the "yellow" clouds, which really do appear yellowish to the eye, and are probably made up of dust.

Examples of all these kinds of clouds are seen at every opposition of Mars, and 1954 was no exception, though on the whole it seems to have been a fairly cloud-free year on Mars (in sharp contrast to the Earth). British observers were hopelessly handicapped last summer, both because of Mars' low altitude and because of our own atmospheric conditions, but in 1952 there were some brilliant clouds to be seen from time to time; on April 17, for instance, I recorded a prominent cloud completely hiding the areas known as Hellas and Mare Hadriacum. But it is the yellow clouds which can persist for longest. In 1911, for instance, Antoniadi followed a vast cloud that spread over much of the southern hemisphere, and lingered on for some months before it finally vanished.

If we are right in supposing that the yellow clouds are dust storms, what causes them? It has been suggested that they are blown from the surface of the planet by high winds, but there are grave objections to this idea; winds in the Martian air are very mild by our standards, and a 25-knot breeze would be a positive gale. It is hard to see how a great cloud such as that of 1911 could have been caused in any such way. It is equally hard to find a better explanation unless we return to that hoary old favourite, volcanic action; and the problem remains unsolved.

Now and then, unusual phenomena are seen. On December 8, 1951, an eminent Japanese astronomer, Tsuneo Saheki, recorded a brilliant spot near the area known as Tithonius Lacus, which became brighter than the polar cap; it spread and faded, finally vanishing in less than an hour. It was suggested that the appearance was due to the eruption of a Martian volcano, but to me this seems improbable; to be visible over many millions of miles, such an eruption would have to be truly Titanic. The explosion of an atom bomb was also suggested, while, needless to say, the Flying Saucer enthusiasts had ideas of their own. In all probability, however, the appearance was due to nothing more significant than a prominent, high-altitude cloud.

All things considered, the Martian atmosphere is as interesting as our own. It has its clouds, its meteors and doubtless its auroræ; it, too, shields the planet's surface from the deadly ultra-violet rays emitted by the Sun. Yet from one point of view, it is a disappointment. So far as we are concerned, it is hopelessly thin and oxygen-poor, and its sole function will be to prevent our blood from boiling and our domed colonies from being battered by the cosmical meteoric bombardment. It is quite certain that we shall never be able to breathe it.

The Surface Conditions

We have now reviewed most of the main features of Mars—the polar caps, the dark areas, the ochre deserts, and the atmospheric mantle. The picture that has emerged is that of a world not very unlike the Earth, but in a more advanced state of senility, due entirely to the fact that it is smaller and has thus aged more quickly. What about its temperature? Is it likely to prove a frozen world?

Fifty years ago, the general answer was: "Yes." Nowadays we know better, because the surface temperature has been measured directly with the sensitive

instrument known as the thermocouple, combined with large telescopes such as those of Flagstaff and Mount Wilson. It has been established that on a summer day at the equator, the temperature may rise to over + 80° F., which is warm judged by British standards. Naturally, the thin air is highly inefficient at blanketing in the heat, and even before sunset the temperature has dropped to below freezing; at midnight, the thermometer must register over — 100° F., even at the equator, while the poles are correspondingly colder. For the record, the highest and lowest temperatures ever recorded on the Earth are + 136° F. (Tripoli, 1922) and — 90° F. (Yerkhoyansk, Siberia).

Needless to say, the coldest night ever known in Tripoli would be a furnace compared with the average heat of Yerkhoyansk; yet the most favourable regions of Mars experience a greater temperature range in the course of 24 hours. So far as we are concerned, conditions are therefore highly unpleasant. Only in the full heat of the day will we be able to venture on to the open surface without very efficient insulating suits. Yet we can imagine forms of life that could survive under Martian conditions; animals and plants can live under very rigorous conditions, and life is very good at adapting itself. After all, a camel would soon die if taken to Greenland, while a polar bear would be far from happy if placed in an oasis in the middle of the Sahara. If higher forms of life ever existed on Mars, they might exist now; as the planet aged, and the temperature range increased, life would naturally adapt itself, as the vegetation has in fact done. So far as warmth goes, there is no obstacle to the existence of our friends the Martians. It is the other difficulties—such as the lack of oxygen—which seem to show us that higher forms of life do not exist there.

Dr. de Vaucouleurs has described the climate of Mars as being "of an exaggerated Continental type." That is certainly a very mild way of putting it!

The Canals

So much for the "natural" features of Mars. Let us turn now to what Lowell called the "non-natural" features—in other words, the canals.

The story of the canals begins, so far as we are concerned, in 1877, when Mars was very favourably placed for observation. Using a fine 8¾-in. refractor, Giovanni Schiaparelli, at Milan, drew up charts of the surface that far surpassed any previously made; he also revised the nomenclature (his names are still in use to-day), and his maps stand up to comparison well with modern ones. But in addition to the polar caps and the ochre and greenish areas, Schiaparelli found something else. In his own words:

"All the vast extent of the continents is furrowed upon every side by a network of numerous lines of a more or less pronounced dark colour. . . . They traverse the planet for long distances in regular lines, that do not at all resemble the winding courses of our streams. Some of the shorter ones do not attain 300 miles; others extend for many thousands. . . . Some are easy to see; others are extremely difficult, and resemble the finest thread of a spider's web drawn across the disk."

For some time, nobody else succeeded in seeing these "canali," as Schiaparelli called them (the word means "channels" in Italian). In 1879 and 1881 Schiaparelli himself not only saw more canals, but found that some of them

had the strange habit of becoming twins. Where there had been one canal, two would appear parallel, close together, and apparently precisely similar in every way; sometimes the pair would lie to either side of the original track, sometimes one of the twins would remain on the first site. The scientific name for this behaviour is "gemination." Sceptics have had other terms for it.

It was not until some years later that other observers managed to see the canals; but when they did (Perrotin and Thollon, at Nice, led the way), canals became all the rage. Everybody started seeing them. The canals of Mars were to Gladstone what the Loch Ness Monster was to us twenty years ago, and what Flying Saucers are at the present time—the difference being that the Martian canals definitely do exist, whatever be their nature. One of the main observers of the time was Professor Percival Lowell, who built an observatory at Flagstaff, in Arizona, specially to study Mars, and worked industriously there between 1895 and his death in 1916.

Lowell was nothing if not whole-hearted. He pointed out that the canals appeared to cover the planet from pole to pole in an immense grid; that they never ended abruptly in a desert; and that when they crossed, they did so at circular dark patches which were christened "oases." He firmly believed that what we saw was an engineering project on a vast scale, constructed by the Martians to convey water from the melting polar caps through the arid deserts. Needless to say, he did not consider that the canals were open water-channels. For us to see them at all, even as fine spider-lines, they must have a breadth of many miles. (Evaporation must also be considered.) According to Lowell, a "canal" is made up of a narrow and possibly piped stream, surrounded to either side by an irrigated area.

Like all pioneers, right or wrong, Lowell was hotly attacked. In fact, more nonsense was written about the canals between 1906 and 1939 than about any other scientific subject. There were some who agreed, with Lowell, that the canals could only be explained on the theory of artificiality; others who followed Antoniadi, and denied that the canals existed at all in the form shown by Lowell.

This statement calls for a little comment. It is perfectly true that the human eye does tend to join up disconnected spots and streaks into hard lines—if you doubt me, draw a series of dots and dashes in a rough line on a sheet of paper, and then look at it from a considerable distance. Moreover, Lowell weakened his whole argument by producing linear features upon almost ever other heavenly body that he drew, including Venus, Mercury and the satellites of Jupiter; one is almost surprised that he did not find canals in the Sun! On the other hand, it is no longer possible to dismiss the canals as pure illusions. There is something there, and we must find out what it is.

Photography is of little help. A comparatively faint object such as Mars must have a time exposure; this means that we are at the mercy of the Earth's dirty and unsteady atmosphere, and delicate details such as canals are blurred out. You have probably seen the photographs of Mars taken with the 200-in. reflector. I can see much more detail than that with my own modest 12½-in. reflector. Planetary work is one branch of astronomy in which the camera is still vastly inferior to the human eye.

The best results so far have come from the Pic du Midi, the high-altitude observatory in the Pyrenees, where Dollfus has been studying Mars with a keen eye and a large telescope. He considers that under normal conditions of seeing, the canals appear hard and sharp; under perfect conditions (more accurately, as nearly perfect as conditions ever are), they break down into a fine structure of dots and dashes. There is an analogy for this in the case of the Moon. Some of the lunar craters show dark radial bands extending from the centre to the walls, of uncertain origin; in normal telescopes they appear continuous, but using the 33-in. Meudon refractor, the telescope employed by Antoniadi for most of his work on Mars, I was able to break down some of these bands into distinct fine structure.

Dollfus' results have not met with complete confirmation elsewhere. In 1954, Wilkins, using the 60-in. reflector at Mount Wilson and the 40-in. refractor at Yerkes, saw the canals as hard, sharp lines, as is shown on his drawings. So the whole question remains very much open. My own view is that Dollfus is right; but time will tell.

Planetary astronomers had hoped that in 1956, when Mars will be at its very nearest, the 200-in. reflector on Palomar Mountain would be used to settle the problem. The scheme was for an observer with a smaller telescope to watch Mars, and notify the observer on the 200-in. as soon as conditions were becoming really good; the 200-in. worker would then stop whatever he was doing, and turn the great instrument to Mars. Unfortunately, my latest information from Palomar is that this idea has been more or less abandoned; the astronomers there are too busy with their galactic and nebular observations. It seems a pity, but there it is. Results obtained in 1954 were inconclusive. Owing to Mars' high southern declination, the best views were obtained from South Africa, and many famous astronomers went there specially for the occasion; but investigations have not led to any startling developments, and not until the late summer of 1956 will we have another chance.

Of course, many observers with small telescopes record dozens of canals. It is really remarkable what you can see with a 3-in. refractor when you put your mind to it. I have see drawings of Mars made with tiny instruments that show detail far beyond my own 12½-in.—or, for that matter, beyond the scope of the Palomar 200-in. I am almost surprised that these observers do not see canals without using a telescope at all. It is difficult to take such drawings seriously. I do not for one moment suggest that there is any deliberate dishonesty; I am certain that there is not. On the other hand, it is too easy to see what one half expects to see, and the human eye is easily fooled.

We can, I think, consider as proved that the canals do exist—not in the hard, fine form shown by Lowell, but in the broader and less regular form shown by Dollfus. Moreover, they take part in the seasonal cycle just as the dark areas do; they darken and harden with the arrival of the moisture-laden winds from the melting polar snows. That being so, they need explaining. If we leave Lowell's intelligent Martians out of the picture for the moment, we must return to the most obvious answer—vegetation—particularly as Öpik's argument about covering by dust applies to the canals just as strongly as to the dark

zones. The main problem is how to explain why the vegetation extends in more or less straight lines over such vast distances.

Weird theories have been put forward from time to time. Professor W. H. Pickering, who was undoubtedly a brilliant observer but who had ideas of his own (he was inclined to believe in the existence of insects on the Moon), thought that the canals might be due to vegetation springing up in the paths of storms that moved in straight lines across the Martian surface, shedding rain as they went. Even worse was the suggestion that the canals are caused by meteors striking the surface of Mars and ploughing long furrows in it. Dr. Clyde Tombaugh the discoverer of Pluto, has put forward a much better theory, according to which the "oases," where the canals meet, are craters formed by minor planets striking Mars in past ages, the canals being cracks in which vegetation grows and spreads. Again we are faced with the difficulty of the great breadth of the canals, and the theory has obvious weaknesses; the trouble is that so far, at least, we have not found anything better. All things considered, the Martian canals, even if not the artificial structures that Lowell believed, are probably the most mysterous objects in the entire Solar System.

Life on Mars

Earlier on in my talk, I made some mention of the grotesque and murderous creatures which novelists are so fond of placing upon Mars. Science-fiction writers have their own name for them: B.E.M.s—Bug-Eyed Monsters. As a matter of fact, however, we can dispose of all B.E.M.s without delay. We know a great deal about living matter; we know that vital cells must be based upon the carbon atom, which has a unique ability to link up with other carbon atoms, as well as atoms of other elements, to form the complex molecules that are necessary. We know all the atoms that occur naturally in nature, and so it is logical to assume that any extra-terrestrial life must be fundamentally, though not superficially, similar to that on Earth. A being on another world might have four eyes, five arms and six legs, with a head like a giraffe and a beak like a parrot; but he would still be carbon-based, and he would still need oxygen, of which there is not much on Mars.

Recently, the B.E.M.s of Wells have been replaced by creatures of a different sort—long-haired gentleman attired in natty one-piece suits. I do not propose to do more than touch upon Flying Saucery, for obvious reasons. Mr. George Adamski says he has met a man from Venus; Mr. Cedric Allingham has gone one better, and says he had a long talk with a Martian whom he met on the Scottish coast only this year. Mr. Leonard Cramp knows just how the Saucers work—by creating their own gravity fields; his book even includes a chapter on human levitation and yogiism. Well—only 120 years ago, many thousands of people were intrigued by the weird bat-men put on the Moon by Richard Locke in his famous "lunar hoax" of 1835. No more need be said.

Actually, we know that there are no living beings on Mars built upon our own pattern. To stress this, something must be said about the mechanism of breathing. Oxygen is the vital gas; every wartime flyer will remember that (I once disconnected my oxygen supply by mistake at a height of about 20,000 ft., so I know). When oxygen is drawn in, it mixes with carbon dioxide and

water vapour produced inside the body, and produces a certain pressure inside the lung. The mechanism is adjusted so that the pressure inside the lung is always the same, whatever the gas may be. If we breathe in less oxygen, more carbon dioxide and water vapour will be produced inside the body to maintain normal lung pressure. If we continue taking in less and less oxygen, more and more of the total gas in the lung will be made up of irrespirable carbon dioxide and water vapour; and unconsciousness follows. The critical point above which no outside oxygen at all could be taken in occurs at about 56,000 ft. above the Earth, though of course the oxygen intake would have become completely inadequate long before this. The atmospheric pressure on the surface of Mars is equal to that at about 55,000 ft. above the Earth. Even if the Martian air consisted of pure oxygen, then, we should be unable to breathe it. But the air is not pure oxygen—it is practically pure nitrogen, and clearly it could be of not the slightest use to us. We need say no more about the humanoid Martians either of Lowell (though he did admit that life there might be on an alien pattern) or of the Saucerers.

The same objection applies to animals, but plants are a different matter—and as we have seen, it is almost certain that plant life does exist upon Mars. Terrestrial plants are vital to our existence, since they absorb the carbon dioxide breathed out by animals and re-emit it as oxygen; this is done by the process of photosynthesis, the key to the problem being the green colouring matter, chlorophyll. If we could detect chlorophyll in the spectrum of the Martian dark areas, we should have positive proof of their vegetal nature. Recent work by Russian workers, notably Professor G. A. Tikhoff, indicate that chlorophyll does exist; needless to say, the investigations are extremely difficult and remain unconfirmed this side of the Iron Curtain, which means that they must be treated with great reserve, but there is nothing improbable in them.

When we come to consider the precise form of Martian plant life, we are reduced to pure guesswork. Tikhoff believes that the plants absorb the warming red and yellow solar rays and reflect the blue and green, which accounts well for the characteristic hue of the dark areas; and we can safely assume that the lack of suitable atmosphere rules out advanced forms, such as forests, bushes and highly-developed flowers. Mosses and lichens are much more likely. The whole question has been investigated recently by an eminent biologist who is also an astronomer, Dr. Hubertus Strughold, who concludes that there is no reason why lowly forms of plant life should not manage to survive on Mars.

Voyages to Mars

It is no part of my theme to-night to say much about the prospects of reaching Mars in the near or more distant future. All I am trying to do is to give you some idea of the conditions we are likely to find when we get there. However, one aspect of Martian travel does concern us—because it involves the two tiny satellites, Phobos and Deimos.

Everyone in this room knows that there is a distinct possibility of our building an artificial satellite, a space-station, before setting out on a lunar or Martian trip. The trouble is that the space-station is not going to be easy to construct. We cannot build it on Earth and then put it into a free orbit; that would be

about as practicable as building the roof of a factory in one block and then jacking it up on to the top of the walls. The station will have to be built out beyond the atmosphere, and the technical problems are immense.

Were the space-station already in existence, we might reasonably hope to get to the Moon within ten years or so. The Martians are much better off. They have two perfect natural space-stations in the shape of the moonlets.

These two moonlets were discovered by Professor Asaph Hall, at Washington, in 1877—the same year in which Schiaparelli first drew attention to the canals. Both are minute. Phobos, the inner, is perhaps 10 miles across; Deimos, the outer, more like 5. They are thus by far the smallest known satellites in the Solar System.

Their chief peculiarities are concerned with their orbits. Phobos spins round Mars at a height of only about 3,700 miles above the surface—roughly the distance from London to Aden—and it completes a full revolution round the planet in 7 hours 39 minutes. As the Martian day is 24½ hours, the "month," so far as Phobos is concerned, is shorter than the day. To an observer standing on the surface of Mars, Phobos will appear to rise in the west, gallop across the sky in only 4½ hours, and set in the east, while the interval between successive risings would be only 11 hours on an average. During one passage across the heavens it would, incidentally, go through more than half its cycle of phases from new to full. Deimos lies at some 12,500 miles above the surface—about the distance between England and Australia—and has a revolution period of 30½ hours. As Mars spins on its axis, therefore, Deimos almost keeps pace with it, and would remain above the Martian horizon at any one place for 2½ days on end.

The satellites are far too small to be of much use as sources of illumination. Deimos, indeed, would appear little larger than Venus does from the Earth; to the naked eye, it would hardly show a perceptible disk. But the importance of Phobos and Deimos needs no emphasis. Apart from the Moon, they will probably be the first worlds to be reached by men. A full-scale Martian journey may take place in several hops—one from Earth to space-station; another from space-station to Deimos (or Phobos); and a third from Deimos down to Mars itself. At all events, the view of the Red World as seen from either moonlet will be well worth the journey across the void.

In passing, it has even been suggested that the Martians, too, have their own views about space-stations, and that future travellers are likely to find that Phobos and Deimos are made of metal rather than rock. This is an intriguing idea, but we must, I am afraid, pass it back to the Flying Saucerers.

Conclusion

I hope I have managed to convey to you something of the state of our knowledge concerning our neighbour world—that fascinating planet of ochre dust-deserts, tracts of vegetation and icy polar snows, shining tantalizingly down at us, and circled by its two dwarf moons. Mars sets us many problems; we want to know the truth about life forms there, we want to know if our analysis of the atmosphere is correct, and—most of all—we want to know the truth about those mysterious features, the canals. Some of these puzzles will not be solved until the age of space-travel is with us, instead of just ahead.

But we may allow ourselves a look into the future. Not many centuries ahead, I think, the picture will be very different. Domed cities will have risen from the Martian deserts; the War-God will have yielded up his secrets, and the coming of man will have brought life once more to a world from which all higher forms of life had long since faded away.

DISCUSSION

The discussion opened with a suggestion that, if the "canals" were deep cracks in the surface of Mars, vegetation might grow at the bottom of them. But Mr. Moore pointed out that the temperature at the bottom of a crack would probably be −200° or even −250° F., which would cut out the possibility of life.

To the next question, about an alleged Martian explosion reported from Japan, he replied that a Japanese astronomer, using a 10-in. refracting telescope, saw a bright mark appear near one of the poles, and in 5 or 6 minutes it had become as bright as the polar cap; then it expanded and faded, finally disappearing in less than an hour. On being telephoned by the Press that night, Mr. Moore said that at first a volcanic explosion had been suggested; but, according to a Japanese calculation, it would have had to be more powerful than the Krakatoa eruption. Probably, therefore, it was an exceptionally large and bright cloud. He had seen such a cloud over Hellas in 1952 with a 15-in. reflector; it was white, and as bright as the polar cap, but lasted less than 24 hours.

A questioner suggested that the occasional disappearance of the "violet" layer in the Martian atmosphere was an electro-magnetic phenomenon. Mr. Moore replied that there had been many attempts to correlate Martian and terrestrial weather, including magnetic storms, but the clearing of the violet layer does not often occur, so any apparent correlation would be something of a coincidence.

To a question about Roche's limit to how near a satellite can approach its primary without breaking up, Mr. Moore replied that Phobos lies just outside the danger zone, though it has been said to be gradually spiralling inwards, so it may eventually break up. To another question he replied that a safe estimate of the diameter of Phobos would be 10 to 40 miles—probably nearer 10, and that of Deimos 5 to 20 miles—probably nearer 5. Through the 60-in. telescope at Mount Wilson, it could just be seen that Deimos was not a star.

Other questions were concerned with the re-forming of the polar caps, which Mr. Moore said could not be followed through a complete cycle: and with the reflection of the Sun from water surfaces on Mars, if any. The Russian astronomers have investigated this problem, and consider that a reflection from a water sheet one-quarter of a mile wide should be bright enough to see.

Asked for his opinion whether Mars has already passed through the Earth's present phase of development, Mr. Moore said it was impossible to be sure, as we do not even know how the planets were formed, though on any theory it seems that they were all formed at approximately the same time. All investigations seem to point to the fact that, by the time life appeared on the Earth, Mars had already almost reached the condition it is in to-day. When we get there, we will have to excavate the crust to search for evidence of past life, and this will also give us an immense insight into the past history of the solar system.

Questioned about the exact nature of the violet layer in the Martian atmosphere, Mr. Moore said that some authorities attributed it to ozone, but the layer was more probably due to finely divided matter in suspension.

A questioner wanted to know if the tendency of mosses to spread upwards would account for the spread of vegetation away from the poles, which are at a lower level than the equator. Mr. Moore replied that some changes in the dark areas are seasonal and some are not. The Syrtis Major, for instance, appears to spread after winter is over, but occasionally a dark area will spread so as to become almost unrecognizable. The elliptical Solis Lacus is notoriously variable, and in 1926 and 1941 the whole orientation of the ellipse was altered.

Arrangements for the use of the 200-in. telescope at Palomar during the 1956 opposition, Mr. Moore said in response to an enquirer, were to have been that an observer would watch Mars through a smaller telescope and advise the observer at the big telescope when seeing conditions were about to become good. But now the 200-in. is being modified and the proposal has been abandoned; so the 60-in. telescope at Mount Wilson will be used on Mars. He expected, however, that the most important observational reports during the next opposition would come from France. A. E. S.

POWERED ORBITS IN SPACE

By George F. Forbes

SUMMARY

The equations for a powered space rocket are given in a form suitable for use on either the Digital or the Bush Differential Analyser.

Notation

A = Area swept by ρ.

a = Acceleration caused by the rocket thrust.

h = Tangent of the angle between the thrust direction and the direction of the parent body.

K = Gravitation constant times the mass of the parent body.

s = Distance along trajectory.

t = Time.

x = Rectangular co-ordinate abcissa.

y = Rectangular co-ordinate ordinate.

θ = Polar co-ordinate angle, parent body at origin.

ρ = Polar co-ordinate radius, parent body at origin.

ψ = Angle between thrust direction and parent body direction.

All primes indicate derivative with respect to time.
CGS or Foot Pound Second system to be used throughout.

Various methods have been suggested for obtaining usable amounts of power in a satellite type spacecraft. Chief among these are the various types of thermal nuclear piles and the solar boiler. The nuclear battery, thermo-couples, photo-electric effects, etc., present further possibilities.

Any thermal device by which available energy could be used to propel or manœuvre the satellite would not justify itself. The relatively low velocities of a thermal jet would require proportionately large mass expenditures. This mass might just as well have been in the form of a chemical propellant.

However, if this available free energy could be used as a source of thrust at high mass efficiency, the weight of conventional fuel saved might justify the weight of a propulsion unit. The mathematics involved in such a unit have been discussed elsewhere.[1] For present purposes we need only note that 1/3600th of a g for one day imparts as much change in velocity as 1 g for 24 sec. Of course the presence of a gravitational field might introduce factors of greater importance. In general, the times involved in space travel make the small accelerations extremely useful.

Low thrust continuous propulsion introduces problems of navigation somewhat more formidable than the transitions between conic orbits of free flight craft. Analytic solutions are available for several special continuous thrust trajectories. Such analytic solutions will probably prove less practical than differential analyser solutions of the original differential equations. Several

hundred pounds, or less, of digital differential analyser will probably prove sufficient to calculate present position, target position, and intermittent predicted trajectories. Such a device could be connected directly to a sensitive accelerometer.

If a satellite craft could be constructed in a close-in orbit, a low thrust motor could make of it a sort of "cargo elevator." The velocity and distance of this elevator could be built up until the Sun's force and the motor thrust itself were the larger forces. The thrust could then be given a component to cancel out the Earth's attraction, and the navigation would then become that of a powered orbit about the Sun. Under such conditions the navigation problem would become more important than the efficiency of the propulsive unit.

It is the purpose of this paper to present the powered trajectory equations in a form suitable for differential analyser solution. The material has been dealt with more specifically elsewhere as an illustrative problem for digital differential analyser specialists.[2]

The differential equations for the trajectory of a powered rocket in space are most conveniently expressed in the spiral co-ordinate form of equation (1). In all the mathematics below it is assumed that the thrust is tangent to the trajectory, that is, in the direction of motion or in opposition to it.

$$\frac{\rho''}{\rho'} - h^2\frac{\rho'}{\rho} + \frac{K}{\rho^2\rho'} = \frac{h'}{h} + \frac{\rho''}{\rho'} + \frac{\rho'}{\rho} = \frac{a}{\rho'\sqrt{1+h^2}} \quad .. \quad (1)$$

The polar co-ordinate form of the equation is given in equation (2).

$$\frac{\rho''}{\rho'} - \frac{\rho}{\rho'}\theta'^2 + \frac{K}{\rho^2\rho'} = \frac{\theta''}{\theta'} + 2\frac{\rho'}{\rho} = \frac{a}{\sqrt{(\rho\theta')^2 + \rho'^2}} \quad .. \quad (2)$$

Equation (1) is not suitable for differential analyser work because of difficulties in the neighbourhood of ρ' equal to zero. Equation (2) contains a somewhat difficult term in the denominator. Algebraic manipulation and a change of form permit the equations below. Only (3), (4) and (5) are needed in the generation loop. Those following are auxiliary equations needed to determine other variables.

$$2dA' = a\rho \sin\psi dt \quad .. \quad .. \quad .. \quad .. \quad .. \quad (3)$$

$$d\rho = \frac{2\cos\psi dA}{\rho \sin\psi} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (4)$$

$$\rho d\psi = \frac{K}{2A'}\sin^2\psi dt - \frac{2dA}{\rho} \quad .. \quad .. \quad .. \quad .. \quad (5)$$

$$d\theta = \frac{2dA}{\rho^2} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (6)$$

$$d\left(\frac{1}{h}\right) = \frac{d\psi}{\sin^2\psi} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (7)$$

$$ds = \rho \sin\psi d\theta \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (8)$$

$$dx = \cos\theta ds \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (9)$$

$$dy = \sin\theta ds \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (10)$$

The analyser schematics indicate that a Bush analyser would require fourteen integrators for the generation loop. The unpowered case of the target would require eight integrators. In both cases the auxiliary equations would require eight integrators.

The digital differential analyser would require eighteen, twelve and ten integrators respectively for the same cases. This total of fifty integrators for powered satellite and unpowered target, both under the influence of the same parent body, is well within the sixty integrator capacity of present machines.

For an orbit about the Sun, calculation at six hundred times real time would involve component errors of about 0·01 per cent. of maximum values. This capacity in present machines suggests that suitable analysers will be available when needed.

REFERENCES

(1) "Thrust Available from Electronic Accelerators," G. F. Forbes, *J. Space Flight*, **4**, (10), 1-6 (Dec., 1952).

(2) Digital Differential Analyser Monograph Six, G. F. Forbes, privately published, 10117 Bartee Avenue, Pacoima, California, First Edition, April, 1954. Chapter 26, "A Trajectory Problem," pp. 27-40.

PUBLISHED MATERIAL ON TRAJECTORY OF POWERED ROCKETS

"Equations of Motion of a Rocket in Central Force Space," G. F. Forbes, Thesis, Massachusetts Institute of Technology, Mathematics Department, Jan., 1948.

"The Trajectory of a Powered Rocket in Space," G. F. Forbes, *J.B.I.S.*, **9**, (2), 75-79 (March, 1950).

"Application of General Trajectory Equation," G. F. Forbes, *J.B.I.S.*, **10**, (5), 194-196 (Sept., 1951).

"Take-Off from Satellite Orbit," H. S. Tsien, *A.R.S. Jnl.*, **23**, (4), 233-236 (July-Aug., 1953).

"Inter-orbital Transport Techniques," H. Preston-Thomas, *J.B.I.S.*, **11**, (4), 173-193 (This reference discusses non-thermal devices.)

THE PURIFICATION OF AIR DURING SPACE TRAVEL

By J. B. S. Haldane, F.R.S.

Recent papers by Bowman[1] and Nicoll[2] in this *Journal* do not appear to take cognizance of the facts of human physiology. Bowman states that the maximum concentration of carbon dioxide "which may be comfortably withstood is about 0·3 per cent. by volume," and that "anything in excess of this will produce laboured breathing, headaches, and, if greatly exceeded, even death." This is completely false. Three per cent. of carbon dioxide about doubles the lung ventilation. But the extra ventilation is quite efficient. One no more gets a headache than when one doubles one's carbon dioxide production by walking. Certainly 3 per cent., or even 2 per cent., leads to breathlessness during heavy exercise. Somewhere about 5 per cent. the deep breathing becomes unpleasant, and in 6 per cent. or over, it is hard to think of

anything but breathing, while there may be headache and vomiting on first breathing fresh air. I have, however, slept (though rather fitfully) in air containing over 5 per cent.

Now it is obviously very much easier to remove carbon dioxide from air if it is allowed to rise to 3 per cent., instead of 0·3 per cent. Roughly speaking, the volume of air to be purified per minute is reduced to one tenth.

From the point of view of human respiratory physiology the nearest thing to a spaceship in which men have actually lived for days is a miniature submarine. In 1940, Dr. E. M. Case and I passed 48 hours shut up in the "mock-up" of the living quarters of one of these vessels, in order to prove to the naval officers concerned that this was possible with the amounts of oxygen and absorbent which we had calculated. We conducted air analyses from time to time, and let the carbon dioxide run up to 3 per cent. or so, so as to get the utmost use from our absorbent. We emerged without headaches after 48 hours.

We had experienced certain discomforts which we reported. A Free French destroyer exceeded the speed limit in force in Portsmouth Harbour, so that we no longer rested on an even keel. We were rather cold, and very wet, since the air was not dried. We were stiff, because only one of us could extend his legs at a time. And we were constipated, because the mock-up did not include a force-pump which was part of the ship when completed.

The absorbent which we used is still, for all I know, secret. But it was not lithium hydroxide, and it was dry, not in solution. It may also be a secret whether we used compressed or liquid oxygen. However, we were able to use the oxygen stream issuing from the container to drag air through the absorbent, so that no pump was needed. I may add that the absorbent used was the outcome of considerable research (not by myself) and that lithium compounds had been tried unsuccessfully.

A spaceship could save a good deal of weight by starting full of pure oxygen, perhaps even under slight pressure. But this would of course forbid smoking and the use of many kinds of apparatus, as a good many metals will burn in pure oxygen. The risk is perhaps not worth taking.

On the other hand there is no reason whatever to restrict the carbon dioxide to 0·3 per cent. It may be argued that Case and I were tough. The first astronauts will have to be tough. It may be argued that we should have felt ill after a fortnight. Perhaps we should; I at least would have been crippled with rheumatism. But I think we should have adapted our breathing to the higher level of carbon dioxide. Clearly, however, an indispensable preliminary to space travel would be for a crew to stay on earth in a mock-up of their craft until its oxygen supply or carbon dioxide absorbent ran out. It might even be worth their staying on till they lost consciousness, to convince them that this form of death is not painful. Having lost consciousness both from too little oxygen and too much carbon dioxide I can reassure anyone concerned on this point.

It is ridiculous to apply to a spacecraft standards of hygiene which are desirable in a factory. It may not even be necessary to dry the air. The first men to leave the Earth will be lucky if they have a 90 per cent. chance of coming back alive. By saving weight on their air purification or drying they may be

able to increase the thickness of their craft's skin, the amount of oxygen and absorbent carried, or some other safety factor.

Nicoll's air locks, again, are unnecessarily spacious. The midget submarines had one air lock, of much smaller dimensions. Nevertheless when one of them was rammed, and sank in about 20 fathoms, the officer in charge put an escape apparatus on his unconscious comrade, and got out with him through the hatch, holding his breath during the ascent.

A number of other points in the articles in question are doubtful. For example Bowman states that about 10 g. per day of sodium chloride "is required for human consumption." It isn't. You can get on very well on much less unless you have to sweat.

I trust that these criticisms will be taken in good part, but it is ridiculous to suppose that the first manned craft to leave the earth will be particularly comfortable, and these problems should be discussed in a quantitative way some years before they become urgent. Very likely the bathyscaphes which descend to great depths in the sea are better equipped than were Case and I, for I have been out of touch for ten years. Perhaps they have got dry lithium hydroxide into a physical state where it is as efficient as what we used or more so. Unfortunately many of the men best qualified are gagged to some extent by the Official Secrets Act. But this applies in an even greater degree to rocket design, and I do not believe that the difficulty will be unsurmountable.

REFERENCES

(1) Dr. N. J. Bowman, *J.B.I.S.*, **12**, (3), (4), May and July, 1950.
(2) N. R. Nicoll, *J.B.I.S.*, **13**, (5), Sept., 1954.

ON THE PROBLEM OF COOLING NUCLEAR WORKING FLUID ROCKETS OPERATING AT EXTREME TEMPERATURES*[1]

By H. J. Kaeppeler†

SUMMARY

For an eventual application of nuclear power for rocket propulsion, the solution of the cooling problem for nuclear working fluid rockets is of primary importance. A method for cooling linear heat sources is suggested and studied. Possible local temperature reductions due to dissociation and ionization are studied. A complete heat conduction coefficient is defined. Examples show that even at operating temperatures very much beyond 10,000° K sufficient cooling efficiency may be expected.

Introduction

The thermodynamic properties of working fluids and the problem of cooling nuclear working fluid rockets operating at low pressures and temperatures up to 10,000° *K* were investigated by I. Sänger-Bredt[2,3]. Homogeneous temperature distribution throughout the heating chamber with the exception of the boundary layer was assumed.

* Summary of a paper presented at the 4th International Congress on Astronautics at Zurich, August 1953 (cf. Reference 1).

† Physicist at the Forschungsinstitut für Physik der Strahlantriebe E. V. Stuttgart—Flughafen.

In the present investigations, a cooling method characterized by a spiral motion of the working fluid towards the axis of rotation (heat source) of a cylindrical heating chamber is introduced, resulting in a radial and azimuthal temperature change. This modification of film cooling, commonly known in gaseous discharge technology, was adopted by the author as a basis for the presented investigations due to the following reasons.

In trying to reduce extreme temperatures, certain thermodynamic properties of the working fluid, which might result in local temperature reductions due to strong increase in energy consumption in certain layers, will have to be exploited. These are mainly excitation of discreet energy levels, dissociation and ionization. Included may also be the possible changes of state. When propagating through a thick layer of a fluid, thermal energy will first fill up the translational and then the internal degrees of freedom of the molecules and atoms. Dissociation and ionization will ensue with the energy being preferably distributed over internal degrees of freedom, thus keeping the energy from being put into the translational degrees of freedom. The translational energy left after penetration of this first part of the layer may already be reduced so far that only lower levels of internal energy (e.g. only dissociation) can be filled in the next part, and after that the remainder of the thermal energy may merely heat up a third part of the layer to moderate temperatures. This particularly applies if thermonuclear reactions are considered. If, in a certain layer, strong decrease of translational energy in favour of an increase in internal energy is achieved, the thermonuclear reaction is quenched. Generally, the re-emitted energy is not great enough to produce the originally high translational temperatures to re-initiate the thermonuclear reaction.

This picture is not changed if it is taken into consideration that these individually treated parts of the layer constitute a body heating up adjoining parts by interchange of translational and internal energy. If the heat flux is constant and continuous, and an appropriate continuous motion of the fluid against the heat source is maintained, the temperature at a certain fixed distance from the heat source may not change with time, i.e. the phenomenon occurs in its steady state, whereas the temperature decreases with increasing distance from the heat source, characterized by strong local temperature gradients. Confining this to a cylindrical heating chamber, the fluid mainly will have a radial motion towards the axis. Technically, the more easily accomplished and more stable spiral motion will be preferred (Fig. 1). In the present analysis, the working fluid is assumed not to participate in the heat generating process. The investigations concerning the case of the working fluid participating in the heat generating process will be presented in a later paper.

The Complete Heat Conduction Coefficient

In the derivation of a differential equation for the transport of thermal energy for the process described above, the working fluid is to be considered as a complex due to the extreme operating temperatures. As the complex is a mixture of neutral gas, electron gas, ion gas, a gas consisting of excited atoms and ions, and a gas consisting of light-quanta, the energy transport due to atoms and ions, due to free carrier electrons and radiation is to be considered

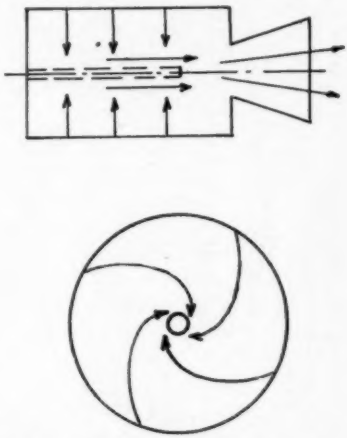


FIG. 1. Flow of working fluid through the heating chamber.

primarily. In this suggested cooling process, the working fluid will be heated from very low temperatures to extremely high temperatures maintained near the heat source. During the stationary process, the temperature near the chamber walls should be well below the dissociation level. Thus, a strong energy transport due to diffusion of recombinable particles (ions and electrons, atoms combining into molecules) will exist and in addition to the above considered modes of heat transport, the conduction of dissociation and ionization energies through diffusion of particles to colder areas has to be taken into consideration for this complete heat conduction coefficient. Hence,

$$K = k_a + k_{dis} + k_{ion} + k_{el} + k_{rad}, \qquad .. \quad .. \quad .. \quad (1)$$

where k_a is the conductivity of the atoms and ions; k_{dis}, k_{ion}, k_{el}, and k_{rad} are the energy transport constituents due to dissociation, ionization, free carrier electrons and radiation. The expressions used in Reference 1 for these constituents are:—

for the translational energy transport of atoms and ions and for carrier electrons,

$$k_a = \frac{k^{3/2}\, T^{1/2} f}{4.3.\pi^{1/2}\, M^{1/2}.q}, \qquad \frac{k_f}{2} = c_1, \quad .. \quad .. \quad (2)$$

$$k_{el} = \frac{\sqrt{2}\, k^{3/2}\, T^{1/2}}{\pi^{1/2}\, m^{1/2}\, q} \frac{n}{N-n}, \qquad .. \quad .. \quad .. \quad (3)$$

for radiation,

$$k_{rad} = \frac{4\pi^2 k^4\, T^3}{45\, \hbar^3\, c^2\, \rho.\alpha}, \text{ with } \alpha = \frac{Z\, \hbar^2\, e^6}{c\, m^{3/2}\, M^2} \frac{\rho}{(kT)^{7/2}} \quad .. \quad (4)$$

and for the transport of dissociation and ionization energy,

$$k_{dis} = eV_{dis}D_{ion}\frac{dn}{dT} \quad \text{and} \quad k_{ion} = eV_{ion}D_{ap}\frac{dn}{dT}. \qquad .. \quad (5)$$

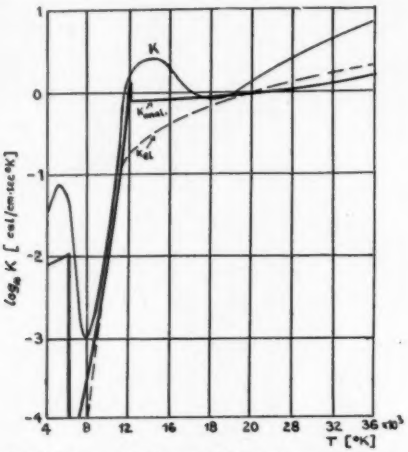


FIG. 2. The complete heat conduction coefficient for oxygen at a pressure of 1 atm.

Here, k is the Boltzmann constant, T the temperature in °K, f the number of the quasi-degrees of freedom, c_i the internal specific heat [erg./° K], M the mass of the particles in the fluid [gr], q the mean collision cross section [cm.^{2}], e the electronic charge, eV_{dis} and eV_{ion} the dissociation and ionization energies [electron-volts], D_{ion} the ionic diffusion coefficient [cm.^{2}/sec.] D_{ap} the ambipolar diffusion coefficient [cm.^{2}/sec.], $\hbar = h/2\pi$ is Planck's constant divided by 2π [erg./sec.], c the velocity of light [cm./sec.], ρ the density of the fluid [gr./cm.^{3}], α the mass absorption coefficient [cm.^{2}/gr.] for a non-degenerate, non-relativistic gas, Z the effective nuclear charge (i.e., number of protons of the nucleus in interaction with radiation) and m the electronic mass [gr.]. For further details, especially bibliography, on this subject, refer to Reference 1. For substitution into the heat transport equation, an approximation of this complete heat conduction coefficient by the analytical function

$$K = C.T.e^{\epsilon T^2} \quad .. \quad .. \quad .. \quad (6)$$

was made. The coefficients for this function in the case of oxygen as a working fluid (which is arbitrarily selected without consideration of technical application) at a pressure of 1 atm. were found to be

$C = 0{\cdot}15 \times 10^{-6}$ [cal./cm./sec. ° K.], $\epsilon = 1{\cdot}3 \times 10^{-7}$ [° K^{-2}]
for the range of $O < T < 5000$ ° K.,
$C = 0{\cdot}571 \times 10^{-7}$, $\epsilon = 6{\cdot}0 \times 10^{-8}$ for $5000 < T < 12000$ ° K.,
$C = 0{\cdot}571 \times 10^{-4}$, $\epsilon = 9{\cdot}0 \times 10^{-11}$ for $12000 < T < 10^5$ ° K. (7)

The complete heat conduction coefficient for oxygen, together with the partial heat conduction coefficient due to free electrons and the analytical approximation are presented in Fig. 2. The inverse temperature conductivity

$$\Lambda = \rho.c_p/K \quad .. \quad .. \quad .. \quad .. \quad .. \quad (8)$$

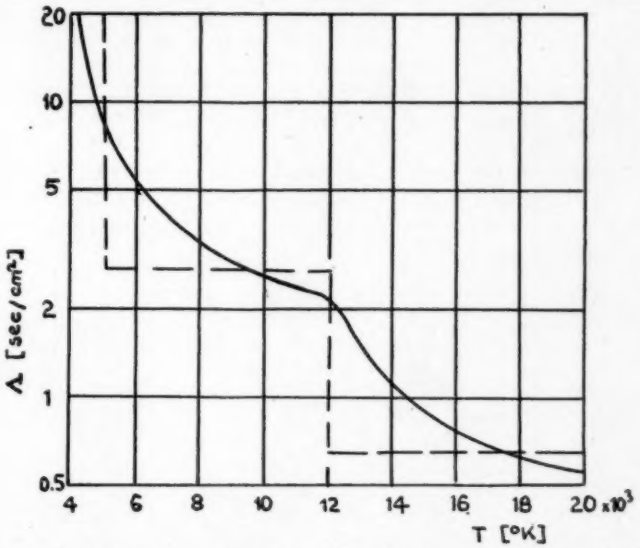


Fig. 3. The inverse temperature conductivity of oxygen at a pressure of 1 atm.

presented in Fig. 3 for the case of oxygen at a pressure of 1 atm., also appears in the solution of the heat transport equation. This factor is kept constant for certain ranges as shown by the dotted lines in Fig. 3.

An Approximate Expression for the Velocity of the Working Fluid Flow

If the differential equation for the heat transport in the working fluid with spiral motion is to be solved analytically, a very simple expression for the velocity distribution, namely a function of r^{-1} (r being the radius in cm.), is required. The investigations, presented in detail in Reference 1, lead to the simple expression

$$v = \frac{r_a}{r} v_o = \frac{R_a}{R} v_o. \quad .. \quad .. \quad .. \quad .. \quad (9)$$

The relation between the radius r and the angle of azimuth ϕ is given by

$$r = r_a e^{-a(\phi - \phi_o)} \quad \text{or} \quad R = R_a e^{-a(\phi - \phi_o)}, \quad .. \quad .. \quad (10)$$

where

$$a = [4.\pi.z.v_o^2 V/\dot{V}^2 - 1]^{-1/2} \quad .. \quad .. \quad .. \quad .. \quad (11)$$

is an abbreviation. In the above equations, $R = r/r_K$ is the reduced radius, r the radius [cm.], r_a the perimeter radius [cm.] (chamber walls), r_a the radius of the heat source [cm.], $R_a = r_a/r_K$, ϕ the angle of azimuth, ϕ_o the initial angle of azimuth, v the fluid velocity, v_o the initial velocity at $r = r_a$ and $\phi = \phi_o$, v_r the radial velocity component, v_ϕ the azimuthal velocity component [all

velocities in cm./sec.], $V = 2.\pi r_a^2 z$ the chamber volume [cm.^{3}] and V the volumetric fluid flow [cm.^{3}/sec.]. The relations between the two velocity components are

$$v_r = -a.v_\phi, \qquad .. \quad .. \quad .. \quad .. \quad (12)$$

where a is the abbreviation given by (11).

Determination of the Radial Temperature Distribution

Together with the analytical expressions for the complete heat conduction coefficient and the velocity distribution, the differential equation for the heat transport in this process

$$\frac{\partial}{\partial t}(\rho X) = \operatorname{div}(K \operatorname{grad} T) + W - \operatorname{div}(\rho v.X), \quad X = \int c_p dT, \quad .. \quad (13)$$

can be solved analytically. Here, ρ is the density of the fluid [gr./cm.^{3}], T the temperature [° K.], X the enthalpy [cal./gr.], K the complete heat conduction coefficient [cal./cm./sec./° K.] and v the fluid velocity [cm./sec.]. With the hydrodynamic equation of continuity

$$\operatorname{div}(\rho v) - \frac{\partial \rho}{\partial t} = 0,$$

and eqs. (6), (8), (9) and (12), the differential equation can be reduced to

$$-2\epsilon T e^{\epsilon T^2} \frac{d^2T}{dR^2} - 2\epsilon T e^{\epsilon T^2} \frac{1}{R}\frac{dT}{dR}[1 + 2\alpha] - [2\epsilon e^{\epsilon T^2} + (2\epsilon T)^2 e^{\epsilon T^2}]\left(\frac{dT}{dR}\right)^2 = \frac{2\epsilon\, r_K^2}{C(1 + a^2)} W,$$

with

$$\alpha = \frac{\dot{V}}{2\pi z}\Lambda - \frac{\dot{V}^2}{8.\pi^2 z^2 r_a^2 v_o^2}\left[1 + \frac{\dot{V}}{\pi z}\Lambda\right] \quad .. \quad .. \quad (14)$$

being an abbreviation. W is the energy generated in the source per unit volume and time [cal./cm.^{3}/sec.], the other notations as explained above. In a plasma, W can be represented by the expression

$$W = \frac{\sigma}{e^2} F^2, \quad .. \quad .. \quad .. \quad .. \quad (15)$$

where σ is the electric conductivity, e the electronic charge, F the constant field constituent. Using the Wiedemann-Franz law and the analytical expression for the heat conduction coefficient, eq. (6), F becomes

$$F^2 = \frac{W(T_o)2k^2}{C} e^{-T^2_o} = \frac{2k^2 E}{\pi r_K^2 z C} e^{-\epsilon T^2_o}, \quad .. \quad .. \quad (16)$$

where E is the energy production in the source per unit time [erg./sec.], T_o [° K] the temperature of the heat source and k is Boltzmann's constant. With the abbreviation

$$\delta = \sqrt{(2/\pi z)}.e^{-\epsilon T^2_o/2}\left[E\,\frac{1}{1+a^2}\,\frac{\epsilon}{C}\right]^{1/2} \quad .. \quad .. \quad (17)$$

and the new independent variable $U = e^{\epsilon T^2}$, the differential equation becomes

$$\frac{d^2U}{dR^2} + [1 + 2\alpha]\frac{1}{R}\frac{dU}{dR} + \delta^2 U = O,$$

with the solution $$U = e^{\epsilon T^2} = R^{-\alpha} Z_\alpha (\delta R),$$

resulting in the radial temperature distribution:

$$T = [\epsilon^{-1}\{\ln[J_\alpha(\delta R)] + \ln A - \alpha \ln R\}]^{+1/2} \quad .. \quad (18)$$

In this equation, $J_\alpha(\delta R)$ is the Bessel-function and A the constant of integration. For the determination of this constant, not the general solution of the differential equation but a particular solution is considered. T_0 is considered to be the maximum temperature of the fluid obtainable after an enthalpy X_0 is imparted on the system. With $X_0 = E/\dot{G}$ ($\dot{G}$ = mass flow rate [gr./sec.]), the pertinent temperature T_o is obtained from an enthalpy-diagram. The constant A is then determined from (with $R = r/r_K = 1$)

$$e^{\epsilon T^2_0} = A \,.\, J_\alpha(\delta). \quad .. \quad .. \quad .. \quad (19)$$

Thus, all relations necessary for determining the radial temperature distribution are given.

Three Examples for the Temperature Distribution

Three examples are presented for a nuclear working fluid rocket with oxygen as a working fluid, operating at a chamber pressure of 1 atm. Type of working fluid, chamber pressure and energy production rate are arbitrarily selected without consideration of actual technical realization.

Example I: Required exhaust velocity 17,000 m./sec., weight flow rate of working fluid 20 kg./sec., resulting thrust 35,000 kg. Perimeter radius of chamber $r_a = 50$ cm., length of chamber $z = 200$ cm., radius of heat source (arbitrary selection) $r_K = 1$ cm., injection velocity of working fluid $v_o = 10$ cm./s. Energy production of heat source $E = 7 \times 10^8$ cal./sec., maximum fluid temperature T_o (at $r = r_K$) $= 2 \times 10^4$ ° K.

Example II: Required exhaust velocity as for example I, chamber data from example I; weight flow of working fluid 40 kg./sec. Energy production $E = 27 \times 10^8$ cal./sec., maximum fluid temperature $T_o = 100{,}000$ ° K. All other data as in the first example.

Example III: Required thrust 400,000 kg. Weight flow of working fluid 120 kg./sec. Energy production of heat source $1{\cdot}5 \times 10^{10}$ cal./sec., maximum fluid temperature 250,000° K. All other data as in the first example.

The radial temperature distributions for these examples are presented in Fig. 4. For the latter two examples, only the temperature distributions above 12,000 ° K. are given, as this range is of the most interest.

Discussion of Results

The presented analysis points a way in which the temperature of working fluids heated by nuclear energy may be reduced below 10° K. near the chamber walls. It is shown that clearly an ionization and a dissociation layer is formed in the working fluid. The temperature drops considerably directly

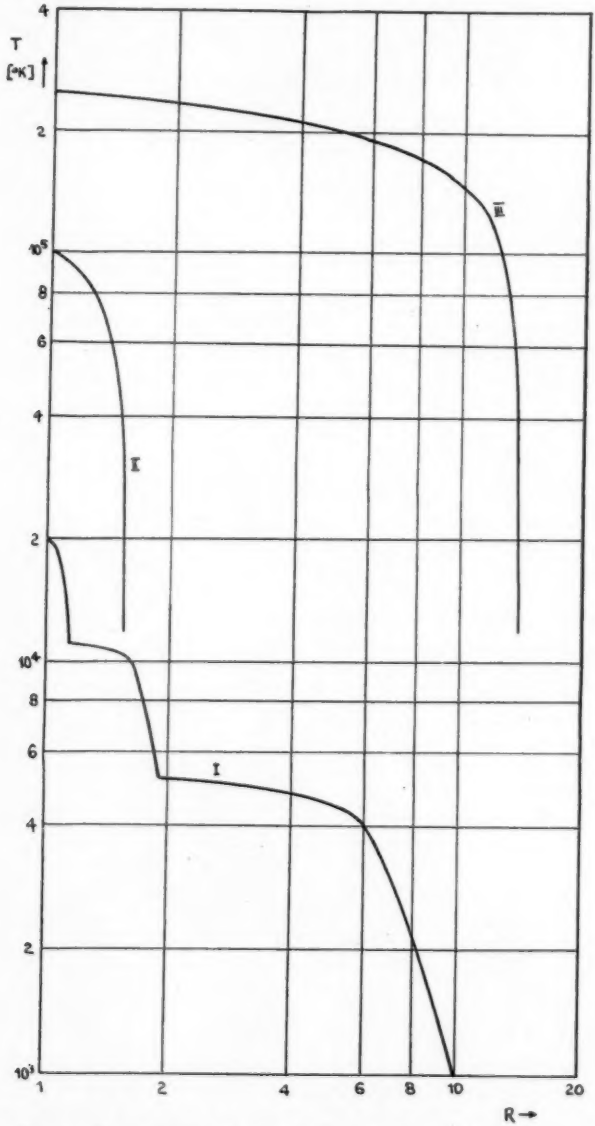


FIG. 4. Three examples for the radial temperature distribution.

behind these layers. This can be explained by the high energy consumption (from translational energy) required for ionization and dissociation. Furthermore, with this decrease in temperature behind these layers, a strong decrease of the complete heat conduction coefficient is noted which further increases the temperature drop.

The third example already constitutes a strong extrapolation from the presented data. It is assumed, that the heat conduction coefficient is mainly governed, and strongly increased, by radiation alone and rather high values are taken for this coefficient in this range. For a more accurate analysis, a detailed consideration of the effects of multiple ionization must be made. Also, the mean mass absorption coefficient as given in this analysis is not accurately valid. Band and line absorption of thermal radiation has to be considered, especially photo-ionization and possibly also photo-dissociation due to the very low density at the extreme temperatures. Finally, the achievement of full thermodynamic equilibrium for all degrees of freedom was assumed. This, in all likeliness, will actually not be the case. Rather, transient thermodynamic states will have to be considered. It is very likely that the consideration of transient states instead of equilibrium will yield even more favourable results, as then the energy transport due to diffusion of recombining particles (particularly electrons and ions) will be reduced considerably.

Detailed studies are required for ascertaining the behaviour of primary and secondary radiation, particularly for strong temperature gradients at ionization layers. Most short wave radiation, however, will likely be reabsorbed so that no danger of too strong penetration should occur.

Experimental studies of this theoretical analysis can easily be made, using a fluid stabilized electrical discharge in a vessel similar to Fig. 1, as outlined in Reference 1.

The presented analysis merely intends to outline a few interesting considerations on the problem of reducing temperature in a working fluid of nuclear rocket power plants and thus only constitutes a first step into the most intricate problem of cooling such power plants operating at extreme temperatures. It seems that the solution of this problem is very closely related to a detailed solution of the processes involved with the transport of energy in a gas plasma.

The author wishes to thank Drs. Eugen Sänger and Irene Sänger-Bredt for their interest in this work and for many helpful suggestions.

REFERENCES

(1) H. J. Kaeppeler: Zum Problem der Kuehlung von Atomraketen bei Verwendung thermonuklearer Reaktionen. In: Probleme der Weltraumforschung, Laubscher, Biel-Bienne, 1954 (in print).
— : Zum Problem der Kuehlung thermischer Atomraketen bei extrem hohen Arbeitstemperaturen. Forschungsreihe GfW, *Bericht* No. 12, Stuttgart 1953.
(2) I. Sänger-Bredt: Zur Thermodynamik der Arbeitsgase von Atomraketen. *Z. Naturforschg.* vol. 8a, 1953, pp. 796–804.
(3) I. Sänger-Bredt: Wasserstoff bei hohen Temperaturen. *Z. Naturforschg.* vol. 6a, 1951, pp. 103–112.
(4) H. Maecker: Der elektrische Lichtbogen. *Ergebn. d. exakt. Naturwiss.*, vol. 25, Springer, Berlin, 1951, pp. 293–358.

The Douglas Skyrocket

On November 20, 1953 the Douglas D–558–2 Skyrocket piloted by Scott Crossfield attained a speed of 1,327 m.p.h. Previously, this aircraft had reached an altitude of 83,235 ft., exceeding the previous altitude record of 72,394 reached by a manned balloon in 1935. The previous altitude record for piloted aircraft was 59,445 ft.

Take-off of the Wasserfall ground-to-air guided missile developed by Elektro-mechanische Werke at Karlshagen. The motor used nitric acid and Visol as propellants, cooling was regenerative with the acid as coolant.

NOTES AND NEWS

Council 1955/56

The results of the Council elections for 1955–56 were announced at the General Meeting held on February 5, 1955.

The three retiring members of the Council, viz. Messrs. D. J. Cashmore, J. Humphries and Dr. L. R. Shepherd, were re-elected, and Dr. H. P. Wilkins was elected in place of Mr. W. N. Neat, who did not stand for re-election.

At the subsequent Council meeting Dr. L. R. Shepherd was again re-elected Chairman of the Council for a further term.

Pre-War Journal

A number of copies of the December 1937 issue of the *B.I.S. Journal* are available for sale, as they are surplus to requirements.

This journal is a printed publication of 24 pages, and, besides being rare, is of very great interest as indicating some pre-war views on space flight.

Members desiring copies can obtain them from the Secretary price 1s. per copy.

21st Anniversary Dinner—Souvenir Menu

A few copies of the Souvenir Menu printed for the 21st Anniversary Dinner at the Waldorf Hotel on October 16 are available to members who would like to have them as a reminder of this historic occasion.

Copies are available, price 1s. 6d. each, on application to the Secretary.

From the World's Press

A new altitude record was announced in the late summer of 1954 as being considerably higher than the 83,235 feet reached during 1953. *The Times of Malta* claimed that the pilot was Major Arthur Murray who flew in a Bell X-1a to an altitude of 90,000 feet after being launched at 30,000 feet from a B.29. Major Murray is reported to have said that flying at Mach 2 was smooth but that solar glare was very disconcerting and it was difficult to read instruments and write on a knee-pad even when wearing anti-glare spectacles.

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In December a report in the *British Medical Journal* received prominence in the popular press. Mice carried to altitudes of 17 miles in balloons were found to have rather more white hairs some months afterwards than was normal in the breed of black mice used in the experiments. It was thought that this resulted from exposure to cosmic ray primaries.

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First details of the International Geophysical Year 1957–58 appeared during the late summer. According to the *Toronto Globe* solar flare observatories will keep watch on the Sun from N. America and fifteen foreign stations. A warning service will advise all stations of unusual solar activity. Rocket launchings will principally take place in the New World, from the U.S., Greenland, Canada

and Alaska, though some rockets will be fired from the Sahara—probably the "Veronique." Sponsored by the International Council of Scientific Unions, the period 1957–58 has been chosen because it will coincide with a period of maximum solar activity.

* * * *

A number of press visits to Woomera during the Autumn gave rise to interesting features in the Australian newspapers. The associated display, by the Supply and Defence Production Departments of the Federal Government, appeared to have been very much better than anything so far put on in this Country by the Ministry of Supply. *The Yorkshire Post* reported that many new ground facilities have been completed, thus enabling Britain and Australia to step up their missile testing programme. All types of missiles, air-to-air, air-to-ground, ground-to-air, and ground-to-ground are being tested. Three thousand people now live in the town of Woomera which has its own school, bank, fire brigade, cinemas, bakery and shopping centre. Twenty-five thousand Australian gum trees have been planted to improve the landscape.

The *Adelaide Advertiser* also claims that U.S. missiles will soon be tested at Woomera. It was stated that the U.S. is ahead of the joint Anglo-Australian projects as far as missiles for operational use are concerned but that Woomera has "made more progress in planning and experimentation with more advanced types of missiles."

Not all Woomera activities consist of free flights of rockets. The *Adelaide Mail* describes an Australian Rocket Test Vehicle Simulator (ARTVS) as a machine which simulates the flight of a guided missile and which can do the equivalent of 100 rocket trials each day thus saving the expense of firing too many live rounds. A larger machine is reported as being currently under development for more involved missile problems.

* * * *

During the latter half of 1954 five separate news stories of Russian origin came forth concerning Soviet activities in the field of astronautics and rocketry.

The Central Air Club of the Soviet Union announced in June that an Astronautical Section would meet in the Autumn to discuss—according to the *Soviet Literary Gazette*—"the possibility of creating an artificial satellite of the Earth." It was reported also, for example in *Madras Mail*, that "one 'cosmic' ship was already being built and biologists were studying the effects of space flight on human beings." Such stories appearing throughout the Indian press at the same time would appear to be put out mainly for their propaganda value.

In July reports appeared in many newspapers of a prediction by Mr. V. Dobronravov in prominent Moscow journals, that an artificial satellite would be established by 1975 and a circumnavigation of the Moon would take place by 1990. As these are the type of prophecy which so often appears in western journals, even to the time scale, it is doubtful if anything more serious can be read into these reports.

There was also a Radio Moscow broadcast on September 25 which told the world that Soviet scientists had at least caught up with the Americans and had

developed rockets which had attained an altitude of 240 miles. According to the *New York Times*, the claim arose from an interview with Professor Stanyukovitch, who was described as a Soviet rocket expert.

Finally, in December, the reports of Soviet activities came back to earth with news from Sweden that rocket launching bases were being constructed along the Baltic shores. *The Irish Times* stated that these bases were capable of hurtling 800 rockets an hour against the west, but no indication of the size of missile has appeared in any of the press reports so far.

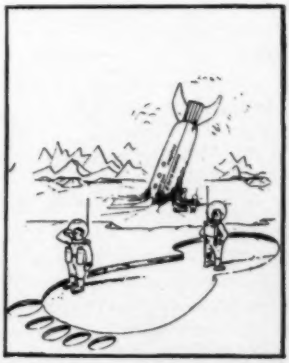
* * * *

During September, at White Sands, the autumn meeting of the American Rocket Society in that area produced some controversy. Mr. Andrew Haley, ARS President, was reported (e.g. by the *Diamond Fields Advertiser*) to have poured cold water on the idea of a manned satellite and its importance to a space flight programme. He is stated to have said that the satellite would have no military advantage and that travel to the Moon will be possible before such a station is likely to be established. At the same meeting, however, Mr. Krafft Ehricke, claimed that the space-station was the first essential step towards space flight. These contrasting views led, of course, to comments such as in the *New York Herald Tribune* that "Leading rocket scientists agree that man will reach the Moon within the next 25 years—but they disagree on the ways to do it."

While the merits of having a space-station for a sub-orbital refuelling technique are admittedly in doubt, there appears a most definite use for a space-station as an astronomical and astrophysical observatory. The *New York Times* reported that Dr. Lyman Spitzer, Jr., speaking at Princeton, emphasized that an observatory above the atmosphere would permit man to see five to ten times as far into space as at present and to see with finer precision.

* * * *

Some newspapers appear to favour reports of activity in the United States and Russia as indicating a "race to the Moon." The *Christian Science Monitor* puts the matter more in its true perspective. "There is much activity now in the spaceship business, not only in the United States but in the Soviet Union. It is increasing. Probably it would be inaccurate as well as flippant to refer to what is going on as a race. But it seems to be established that there are scientific projects under way . . . to launch a device . . . that will become a tiny particle in space travelling in the orbit of the earth."



"Not a sign of life anywhere!"

A number of newspapers have been expressing concern at the possibility of carrying earthly troubles into space and to other worlds. What may perhaps be a more likely happening, and certainly a more enlightened viewpoint, was expressed in the *Christian Science Monitor*, which pointed out that when the New World was discovered, America did not become an extended battlefield for European rivalries, but acted instead as an escape outlet. Moreover, the difficulties, the new challenges and the new-found adventures, acted as safety-valves, keeping the colonists fully occupied in safeguarding their own existence.

* * * *

In Cape Town during August, 1954, a successful symposium was held under the chairmanship of Dr. R. H. Stoy, Her Majesty's Astronomer at the Cape. It was organized by the University of Cape Town's Department of Extra-Mural Studies and sought to show what was fact and what fiction in the many reports of space travel possibilities. A lecture by Mr. J. F. Uys outlined present rocket development and showed how a satellite might be established. Capt. M. J. Metz discussed problems of space medicine.

* * * *

The *New York Times* printed a denial from Dr. Lincoln La Paz that two meteorites revolving in satellite orbits had been discovered by him, but the report added that the search for bodies of that nature was being continued.

* * * *

The Australian *Newcastle Morning Herald* has reported a U.S. Navy development of an inexpensive rocket-boosted parachute that can be shot to a height of 60,000 ft. and act as a target for guided missiles similar to NIKE. The parachute is carried aloft in a 13½ ft. long rocket and bears the code name POGO.

Tailpiece.

Admiral Lord Mountevans, writing in *Courier* for December, 1954, does not believe space travel to be a practical possibility within measurable time. He states "For my part I should like to see some of the ingenuity and scientific knowledge now given to what I believe to be the never-never land problem of interplanetary space flight directed towards defence and, in particular, naval defence problems."

The worthy admiral exhorts us to remember "We are a sea-going not a moon-going people."

We were shattered by this final appeal to the British people and can only assume that it must have arisen from him finding out that the Moon's Mare Imbrium contains no water.

Comment is almost superfluous. But we must express our thanks that there is at least one Navy which has an office of high-altitude research and already has a rocket which reaches beyond the appreciable atmosphere.

Junior Postbag

"We have just formed the x x x x Inter-Planetary Society; can you tell us what to do now?"

DATA SHEETS

By Kenneth W. Gatland

WAC-CORPORAL (U.S.A.)—G.A.L.C.I.T./Douglas Aircraft Co.

(*a*) Role: Research, Upper atmosphere.
(*b*) Initial firing: September 26, 1945.
(*c*) Length: 16·0 ft.
(*d*) Diameter, max.: 12·0 in.
(*e*) Launching weight: 665 lb.
(*f*) Payload weight: 25 lb.
(*g*) Thrust: 1,500 lb. × 45 sec.
(*h*) Velocity, max.: 4,100 ft./sec.
(*i*) Propellant: nitric acid/aniline.
(*j*) Feed system: gas-pressure (compressed-air).
(*k*) Altitude: 19 miles (without booster). 43·5 miles (with booster).
(*l*) Control: none; dynamic stability due to three fixed tail fins plus high initial acceleration.

G.A.L.C.I.T. = Guggenheim Aeronautical Laboratory, California Institute of Technology.

Notes: Launched from 102 ft. vertical tower using solid-propellant booster (modified "Tiny Tim," thrust 50,000 lb. × 0·5 sec.). Development preceded by construction and test (July, 1945) of 1/5th scale model to determine shape and number of tail fins and the effectiveness of missile/booster combination. Parachute recovery of detached nose-cone; later, instrument readings relayed to ground by radio (telemetering).

REFERENCE

(1) "Research and Development at the Jet Propulsion Laboratory, GALCIT," *J.B.I.S.*, **6** (2) Sept., 1946, pp. 34-61.

AEROBEE (U.S.A.)—A.P.L./Aerojet Engineering Corp./Douglas Aircraft Co.

(*a*) Role: Research, Upper atmosphere.
(*b*) Initial firing: November 24, 1947.
(*c*) Length: 18·8 ft.
(*d*) Diameter, max.: 15·0 in.
(*e*) Launching weight: 1,665 lb.
(*f*) Payload weight: 150 lb.
(*g*) Thrust: 2,600 lb. × 45 sec.
(*h*) Velocity, max.: 4,100 ft./sec.
(*i*) Propellant: nitric acid/aniline.
(*j*) Feed system: gas-pressure.
(*k*) Altitude: 70 miles.
(*l*) Control: none; dynamic stability due to three fixed tail fins plus high initial acceleration (approx. 12 *g*. max.).

A.P.L. = Applied Physics Laboratory, Johns Hopkins University.

Notes: Launched from 140 ft. vertical tower using solid-propellant booster (thrust 18,000 lb. × 2·5 sec.). Two methods of recovering research data: radio telemetering and salvage of instruments from impact wreckage of detached nose-cone. When used in medical tests of monkeys and mice, nose-cone recovered by ribbon parachute. Rocket also ship-launched (U.S.S. *Norton Sound*) in cosmic-ray studies made in vicinity of Northern Geo-Magnetic Pole. Approx. cost of vehicle: £9,000 (without instrumentation).

REFERENCES

(1) *Development of the Guided Missile* (2nd edition), by K. W. Gatland, Iliffe and Sons, London, 1954, pp. 176-180, 254-255, 249.
(2) "Research in the Upper Atmosphere with Sounding Rockets and Earth Satellite Vehicles," Dr. S. F. Singer, *J.B.I.S.*, **11** (2) March, 1952, pp. 61-73.
(3) "First Into Space" (Medical Tests of Mammals), *J.B.I.S.*, July, 1952, pp. 194-196; "Rocket Flights of Mammals to 200,000 ft.," *J.B.I.S.*, Jan., 1953, pp. 7-9.
(4) 200 *Miles Up*, by J. Gordon Vaeth, The Ronald Press Co., New York, 1951.

VIKING 9 to 11—Naval Research Lab./Glenn L. Martin Company/Reaction Motors, Inc.

(*a*) Role: Research, Upper atmosphere.
(*b*) Origin: 1952.
(*c*) Length: 42·0 ft.
(*d*) Diameter, max.: 45·0 in.
(*e*) Launching weight: 14,940 lb.
(*f*) Propellant weight: 12,100 lb.
(*g*) Payload weight: 750 lb.
(*h*) Thrust: 20,500 lb.
(*i*) Propellant: liquid oxygen/alcohol.
(*j*) Feed system: turbo-pump (as Vikings 1 to 7).
(*k*) Altitude: 135·6 miles (No. 9).
135·6 miles (No. 10).
158·0 miles (No. 11).

TABLE I

ORIGINAL VIKING SERIES

Viking	Launching date	Site	Summit altitude (miles)	Velocity (cut-off) (m.p.h.)	Vehicle: Length × 32 in. dia. (ft.)	Notes
1	3.5.49	White Sands	51·5	2,350	45·25	Premature cut-off of motor at 53·2 sec.
2	6.9.49	White Sands	32·3	1,830	46·5	Premature cut-off of motor
3	9.2.50	White Sands	50·0	2,350	47·4	Enforced cut-off of motor by radio command due to irregular trajectory
4	11.5.50	Pacific (from U.S.S. *Norton Sound*)	106·4	3,530	48·6	Fired at intersection of Earth's geomagnetic and geographic equators (about 60 miles south of Christmas Island). Highly successful
5	11.11.50	White Sands	107·5	3,500	48·6	Highly successful—results still being studied more than a year later
6	21.11.50	White Sands	40·0	1,640	48·6	Night firing—premature cut-off of motor
7	7.8.51	White Sands	135·6	4,100	48·6	First rocket to exceed record summit altitude of A-4 (116 miles)

NOTES: Design development based on experience with Vikings 1 to 7, with enlarged diameter to accommodate approximately 50 per cent. more propellant. Viking 8, first rocket of revised series, broke away from test-bed during static firing. Approx. cost of vehicle: £143,000 (without instrumentation).

REFERENCES

(1) *Development of the Guided Missile* (2nd edition), by K. W. Gatland, Iliffe and Sons, London, 1954, pp. 183-184; 250; 274-275.
(2) "The Viking No. 10," *J.B.I.S.*, **13** (4) July, 1954, pp. 213-215.

VIKING 7 (U.S.A.)—Naval Research Lab./Glenn L. Martin Company/Reaction Motors, Inc.

(*a*) Role: Research, Upper atmosphere.
(*b*) Origin: 1951.
(*c*) Length: 48 ft.
(*d*) Diameter, max.: 32·0 in.
(*e*) Launching weight: 9,510 to 10,410 lb.
(*f*) Propellant weight: 7,930 lb.
(*g*) Payload weight: 100 to 1,000 lb.
(*h*) Thrust: 20,500 lb. × 75 sec.
(*i*) Velocity, max.: 5,000 ft./sec.
(*j*) Propellant: liquid oxygen/alcohol.
(*k*) Feed system: turbo-pump (hydrogen peroxide steam generator).
(*l*) Altitude: 135·6 miles (with 425 lb. payload).

NOTES: Take-off from simple platform as German A-4. Stabilized by exhaust deflection; rocket motor is gimbal mounted, moving bodily in pitch and yaw to steer the vehicle under gyro-control. Rocket motor developed by Reaction Motors, Ltd. Roll correction by (H_2O_2) tangential jets. Objectives of programme: to extend knowledge of—

(*a*) the physical state of the Earth's atmosphere to as great an altitude as possible, principal objects to study being temperatures, pressures, densities, and composition;
(*b*) fundamental nature and properties of the ionosphere and those processes which lead to its formation;
(*c*) solar and terrestrial radiations; and
(*d*) the physics of high-energy particles by high-altitude cosmic-ray studies.

Two methods of recovering research data: radio telemetering and salvage from impact wreckage of actual instruments, etc. from detached nose-cone. For details of Vikings 1 to 6, see Table I.

REFERENCES

(1) *Development of the Guided Missile* (2nd edition), by K. W. Gatland, Iliffe and Sons, London, 1954, pp. 183; 250; 274-275.
(2) 200 *Miles Up*, by J. Gordon Vaeth, The Ronald Press Co., New York, 1951.

KNOW YOUR COUNCIL

In previous *Journals* (November 1948 to November 1949) we have presented a series of short biographies of various Members of the Council. These proved very popular with many members, especially in the provinces—overseas, who could not have the opportunity of meeting Members of the Council personally, and in response to a number of requests we are now taking this opportunity to bring the series up to date again.

D. HURDEN, B.A., G.I.Mech.E. Born 1924 and educated at Uppingham and New College, Oxford. Took his degree in Engineering Science in 1944 and joined Armstrong Siddeley Motors Ltd. to do experimental work on aircraft piston engines. In 1946 he began to do small-scale experimental work on rocket motors, and in 1947 was transferred to this work altogether. He is now Engineer in charge of development and experimental work in Armstrong Siddeley Motors Ltd. Rocket Division.

Mr. Hurden has had a mild interest in interplanetary travel since reading science fiction as a boy, but did not join the B.I.S. until he began to work on rockets. He is still interested mainly in the propulsion side, but in spite of this has given a number of talks on interplanetary travel to various organizations in the Midlands and enjoys doing this. Two of his more technical lectures have been published in the *Journal* of the B.I.S., and he was the author of a short introduction to rocket engineering, published in one of the Penguin "Science News" series.

He was elected to the Council of the B.I.S. in 1953.

Other interests include music, the theatre, philately and model engineering.

DEREK FRANK LAWDEN was born at Handsworth, Birmingham, on September 15, 1919. He was educated at King Edward's Grammar School, Aston, where his interest in mathematics and science steadily increased. Until the age of fourteen he was determined to qualify as an engineer and spent most of his spare time Meccano model building. This phase was followed by another which lasted until he was sixteen, and during which a career in chemistry seemed attractive. However, the head of the mathematics department strongly advised him to specialize in this subject and he has never regretted accepting this advice.

In 1937 he entered St. Catharine's College, Cambridge, with an Exhibition. One of his interests whilst at the University was the O.T.C., so that at the outbreak of the war he volunteered for service in the arm in which he had been trained, the Royal Artillery. After being commissioned in 1940, he first served in a Survey Training Regiment at Larkhill, and then, after qualifying as an Instructor of Fire Control, spent two years at Gibraltar (1942-44) as the I.F.C.(C.A.), being responsible for the Coast Artillery radar. The latter part of the war he spent at the Military College of Science (which was then housed in the Technical College at Bury, Lancs.) as a lecturer in computing instruments and mathematics.

Upon release from the Army in 1946, he returned to St. Catharine's to complete his degree course, being classed as Wrangler in 1947.

After being appointed a civilian lecturer in mathematics at the Military College of Science in 1948, he spent three years in this post before returning to his home town as a Senior Lecturer in mathematics at the College of Technology. He is at present continuing in this appointment.

An interest in space travel was first stimulated by a reading of Wells' *First Men on the Moon*, though the realization that the opportunity to penetrate into space might actually be afforded his own generation only came with his discovery of Cleator's *Rockets Through Space*. Application for membership of the B.I.S. followed immediately and he was accepted in 1939.

Since the reformation of the B.I.S. after the last war, he has devoted much of his spare time to a programme of research which he hopes will eventually yield a comprehensive theory to act as a basis for the calculation of rocket trajectories in space and for navigation along these paths. When fully worked out, the theory will be published in book form. Meanwhile, he is planning to write a series of texts dealing with the application of mathematical methods to engineering problems. The first of these, *Mathematics of Engineering Systems*, has already been published and concerns the theory of automatic control systems and associated devices.

ABSTRACTS

Edited by J. HUMPHRIES

A complete list of references to the various items abstracted below will appear in the Annual Index.

AIRCRAFT

(54) **Rocket assistance for helicopters.** *Flight*, **66**, 502 (*Sept.* 29, 1954). A small hydrogen peroxide unit produced by Reaction Motors. It is used on the tips of helicopter rotors as a means of assisted take-off.

(55) **A rocket-powered helicopter.** *Aeroplane*, **87**, 574 (*Oct.* 15, 1954). Description of Rotor-Craft RH-1, which is claimed to be the world's first one-man, strap-on, rocket-powered helicopter. Powered by hydrogen peroxide motors at the rotor-tips, it has a duration of 8 to 9 minutes and a man can easily walk with it strapped to his back.

ASTRONAUTICS

(56) **Utilization of radio frequencies in connection with rockets.** G. E. Sterling. *Jet Propulsion*, **24**, 322-323 (*Sept.-Oct.*, 1954). Discusses technical and political problems of communication with artificial satellites.

(57) **The vulnerability of satellite vehicles to countermeasures.** L. H. Thomas. *Jet Propulsion*, **24**, 321-322 (*Sept.-Oct.*, 1954). Suggests that a satellite vehicle could be rendered useless by exploding a warhead containing small shot in a counter-orbit. The shot would have an attack velocity of twice orbital velocity. (2 *refs.*)

(58) **A new supply system for satellite orbits.** K. A. Ehricke. *Jet Propulsion*, **24**, 302-309, 369-373, 365 (*Sept.-Oct. and Nov.-Dec.*, 1954). The system described is characterized by operational separation of cargo supply and passenger transport. The supply ship has a ballistic shape and is automatically guided into the target orbit. The passenger ship is equipped with a winged upper stage. Next supply requirements for orbital operations as well as space-flight are discussed. The existence of optimum satellite orbits for departure and arrival of interplanetary expeditions is demonstrated analytically. Finally, examples of guided supply vehicles and passenger ships are presented. Their take-off weight and payload capacity serve to illustrate the effect of supply requirements on the over-all supply efforts. (13 *refs.*)

(59) **The Fifth International Astronautical Congress.** E. Burgess. *Aircraft Engng.*, **26**, 357-359 (*Oct.*, 1954). Summaries of a selection of papers read at the Congress.

(60) **The growing interest in space travel.** *Aero. Engng. Rev.*, **13** (11), 67-68 (*Nov.*, 1954). A report on the Fifth International Astronautical Congress.

(61) **Satellite orbits for interplanetary flight.** K. A. Ehricke. *Jet Propulsion*, **24**, 381-382 (*Nov.-Dec.*, 1954). Comments on earlier articles. (3 *refs.*)

ASTRONOMY

(62) **Problems of Mars.** A. P. Fitzgerald. *Irish Astr. J.*, **3** (2), 37-52 (*June*, 1954). General account with photographs taken at Flagstaff and the Pic du Midi.

(63) **Some Lunar curiosities.** P. Moore. *Vega*, **1**, 64-67 (*July*, 1954). Discussion of some remarkable natural features of the Moon's surface.

(64) **Interpretation of some Martian features.** D. B. McLaughlin. *Publ. Astr. Soc. Pacif.*, **66**, 161-171 (*Aug.*, 1954). Suggests that the main dark areas on Mars are composed of ash ejected from active volcanos.

(65) **The atmospheres of Jupiter and Saturn.** O. Struve. *Sky and Telescope*, **13**, 336-338 (*Aug.*, 1954). Recent studies of the outer envelopes.

(66) **Radio studies of interstellar hydrogen.** B. J. Bok. *Sky and Telescope*, **13**, 408-412 (*Oct.*, 1954).

(67) **Further note on Martian features.** D. B. McLaughlin. *Publ. Astr. Soc. Pacif.*, **66**, 221-230 (*Oct.*, 1954). Sequel to article in **66**, 161-171 (*Aug.*, 1954). (See abs. no. 64.)

(68) **Cosmic dust.** O. Struve. *Sky and Telescope*, **13**, 415-418 (*Oct.*, 1954). General discussion of the problems concerning interstellar matter, both in the solar and the stellar system.

ATMOSPHERE

(69) **Rocket research in the upper atmosphere.** R. L. F. Boyd. *Sci. Progr.*, **42**, 435-448 (*July*, 1954). General review of progress. (4 *refs.*)

BIOLOGY AND MEDICINE

(70) **Man and machine between atmosphere and space.** H. Haber. *Aero. Engng. Rev.*, **13** (11), 56-62 (*Nov.*, 1954). Reviews problems connected with future flight at extreme altitude and concludes that, barring weightlessness, problems will differ from to-day's by degree only.

MATERIALS

(71) **Short-time, high-temperature properties of heat-resisting alloy sheet.** H. C. Cross, R. C. McMaster, W. F. Simmons and J. A. van Echo. *Rand Corp. Rept. No. RA-15077* (*Feb.* 27, 1948).

(72) **Short-time, high-temperature properties of heat-resisting alloy sheet.** W. F. Simmons, J. A. van Echo and H. C. Cross. *Rand Corp. Rept. No. R-147* (*June*, 1949).

(73) **Thermal properties and applications of high-temperature aircraft insulation.** P. Greebler. *Jet Propulsion*, **24**, 374-378 (*Nov.-Dec.*, 1954). Fundamental principles of heat transfer in fibrous insulations are discussed and some specific applications considered. (9 *refs.*)

PHYSICS

(74) **Viscosity and density of the nitric acid-nitrogen dioxide-water system.** D. M. Mason, I. Petker and S. P. Vango. *Calif. Inst. Tech., Jet Prop. Lab. Prog. Rept. No.* 20-214, 33 pp. (*Jan.*, 1954). Measurements were made at 0°, 25° and 40° C. for compositions in the range from 75 to 100 per cent. HNO_3, 0 to 20 per cent. NO_2 and 0 to 5 per cent. H_2O.

(75) **The thermal expansion of some liquids of interest as rocket fuels.** G. G. Kretschmar. *Jet Propulsion*, **24**, 379-381 (*Nov.-Dec.*, 1954). The volume temperature expansion coefficient has been determined for nitromethane and three dilutions of hydrazine over the temperature range 0° to 75° C. (4 *refs.*)

(76) **Liquid jet atomization by a sonic nitrogen stream.** K. R. Stehling and R. W. Foster. *Jet Propulsion*, **24**, 384-385 (*Nov.-Dec.*, 1954). Penetration of a liquid jet is a linear function of the liquid jet velocity.

PROJECTILES

(77) **Some problems of long-range missiles.** G. A. Crocco. *Aerotecnica*, **34**, 59-71 (*April*, 1954) (*In Italian*). Principles of rocket operation and features of ballistic trajectories are reviewed. Problems of aerodynamic heating during return are examined. The use of the orbital station for military purposes and long-range missiles for civil transport are discussed. Finally, the relations between specific power and maximum speed for chemical and nuclear missiles are analysed.

(78) **Project Nike.** W. H. C. Higgins. *Ordnance*, **39**, 227-231 (*Sept.-Oct.*, 1954). Conception, planning and execution of Nike development project.

(79) **Guided missiles.** G. W. H. Gardner. *Engng.*, **178**, 692-694 (*Nov.* 26, 1954). Lecture delivered to the Institution of Mechanical Engineers. The author takes as an example a ground-to-air weapon and on this basis discusses problems of guidance, high-temperature materials, ram-jets, rocket motors and performance and control of missiles. Concludes with a description of Tridac the new missile simulator.

(80) **Guided missiles.** G. W. H. Gardner. *Aeroplane*, **87**, 757-759 (*Nov.* 26, 1954). For abstract see abs. no. 79.

(81) **Guided missiles.** G. W. H. Gardner. *Engineer*, **198**, 728-732, 765-766 (*Nov.* 26 *and Dec.* 3, 1954). For abstract see abs. no. 79.

(82) **Guided missiles.** G. W. H. Gardner. *Flight*, **66**, 797-799 (*Dec.* 3, 1954). For abstract see abs. no. 79.

RADIO AND ELECTRONICS

See also abs. no. 56.

(83) **Rocket instrumentation for reliable upper-atmosphere temperature determination.** N. W. Spencer, H. F. Schulte and H. S. Sicinski. *Proc. Inst. Radio Engrs.*, **42**, 1104-1108 (*July*, 1954). Design and operational principles and characteristics of the Aerobee research electronics. (5 *refs.*)

(84) **Super simulator.** *Aeronautics*, **31** (5), 75 (*Dec.*, 1954). Description of Tridac the new missile simulator, now in use at the Royal Aircraft Establishment.

ROCKET MOTORS

See also abs. no. 54.

(85) **Means for controlling the direction of a stream of ionised fluid.** M. Kadosch and L. de Jurquet de la Salle. Brit. Pat. No. 711,929 (*July* 14, 1954). Use of a magnetic or electric field to deflect an ionised jet, of particular application to nuclear rockets.

(86) **Some thermodynamic and propulsive considerations of rocket motors.** E. Macioce. *Aerotecnica*, **34**, 196-203 (*Aug.*, 1954) (*In Italian*). After a general consideration of rocket performance the fundamental propulsion equation is derived with reference to relativistic effects. Problem of escape is also dealt with. (13 *refs.*)

(87) **The 350,000-pound thrust rocket test stand at Lake Denmark, N.J.** B. N. Abramson, D. S. Brandwein and H. C. Menes. *Jet Propulsion*, **24**, 291-296 (*Sept.-Oct.*, 1954). The stand is of steel and concrete, the basic structure being a steel cantilever. Firing attitude range is from horizontal to vertical and missiles up to 90 ft. long can be fired. The vertical distance from the motor mounting to the ground is 60 ft. and water for cooling the exhaust is available. The underground control room is 250 ft. distant.

(88) **Unconditional stability of low-frequency oscillation in liquid rockets.** S.-I. Cheng. *Jet Propulsion*, **24**, 310-312, 315 (*Sept.-Oct.*, 1954). The minimum value of the interaction index compatible with unstable oscillations is advanced as the basic criterion of unconditional stability of the system. This value may be obtained for any given system directly from flow tests. The effects of several constants on stability are briefly discussed. The transfer functions of the feedback circuit of a servomechanism actuating a control capacitance next to the injector that will make a given system unconditionally stable is given explicitly in terms of these constants for both monopropellant and bi-propellant systems. (10 *refs.*)

(89) **Flow separation in overexpanded supersonic exhaust nozzles.** M. Summerfield, C. R. Foster and W. C. Swan. *Jet Propulsion*, **24**, 319-321 (*Sept.-Oct.*, 1954). Curves are given for determination of flow separation in a rocket nozzle; these are based on experimental work carried out with a three-dimensional nozzle. Results of work with a two-dimensional transparent nozzle are also given. (4 *refs.*)

(90) **Measuring and recording rocket engine performance.** *Autom. Ind.*, **111** (7), 71, 122 (*Oct.* 1, 1954). The test rig used by Bell Aircraft Corp. consists of a large reinforced bell-crank. The rocket thrusts against the vertical member and the force is transmitted to a load cell placed under the end of the horizontal arm. Thrust is recorded on a high-speed recorder.

(91) **Solid or liquid: it's here to stay.** A. J. Zaehringer. *Aviation Wk.*, **61** (17), 37-38, 40 (*Oct.* 25, 1954). Assessment of present status of aircraft rocket assisted take-off.

(92) **Britain's De Havilland Super Sprite cold rocket hits the silk.** *Aviation Wk.*, **61** (19), 40 (*Nov.* 8, 1954). Photos of Super Sprite being recovered by parachute.

(93) **The mechanics of film cooling. Pt. I.** E. Knuth. *Jet Propulsion*, **24**, 359-365 (*Nov.-Dec.*, 1954). Conditions which insure liquid-film attachment to solid surfaces without loss of unevaporated liquid to the gas stream when simple radial-hole injectors are used have been determined experimentally. A method for calculating the evaporation rate and the surface temperature for a stable inert coolant film is given. (30 *refs.*)

(94) **Transpiration cooling in porous metal walls.** E. Mayer and J. G. Bartas. *Jet Propulsion*, **24**, 366-368, 378, 386 (*Nov.-Dec.*, 1954). The internal heat-transfer equations for a porous medium under transpiration cooling are simplified by approximations valid for porous metals. The temperature distribution problem for porous metal walls is reformulated on the basis of over-all energy balance requirements. The simplified formulation is applied to plane parallel and cylindrical walls subject to boundary conditions corresponding to convective heat transfer and specified temperatures at the wall boundaries. (5 *refs.*)

ROCKET PROPELLANTS

See also abs. nos. 74 and 75.

(95) **Thermal expansion of extruded, solventless, double-base propellants.** R. M. Moon. *NAVORD Rept. No.* 2083 (*NOTS* 819), 42 pp. (*Jan.*, 1954).

(96) **Analysis of double-base propellants by infra-red spectroscopy.** R. W. Philips and R. Steinberger. *Hercules Powder Co., Allegany Ballistics Lab. Rept. No. ABL/P-23*, 14 pp. (*Jan.*, 1954).

(97) **The unsteady burning of cordite.** J. D. Huffington. *Trans. Faraday Soc.*, **50**, 942-952 (*Sept.*, 1954). An investigation into chuffing and of the continuous but oscillatory burning into which chuffing transforms when the nozzle size is reduced. It is concluded that during a chuff the surface layer of the propellant is first liquefied and then immediately burns explosively down to a certain critical depth, the process being repeated during subsequent chuffs. (7 *refs.*)

(98) **An air-transportable liquid oxygen generator—its operation and application.** G. A. Bleyle, R. B. Hinckley and C. L. Jewett. *Jet Propulsion*, **24**, 297-301 (*Sept.-Oct.*, 1954). This unit, which works on a low-pressure cycle, produces 99·5 per cent. pure liquid oxygen at 10 tons/day. It is divided into skid-mounted sections suitable for loading into standard cargo aircraft. (11 *refs.*)

(99) **Performance of ethylene oxide as a monopropellant.** I. Glassman and J. E. Scott. *Jet Propulsion*, **24**, 386 (*Nov.-Dec.*, 1954). Comments on paper by W. C. Robison. *Jet Propulsion*, **24**, 111-112 (*March-April*, 1954). [For abstract see *J. Brit. Interplanet. Soc.*, **13**, 359, abs. no. 340 (*Nov.*, 1954).]

ROCKET PROPULSION

(100) **On thrust and drag in rocket propulsion.** E. Mattioli. *Aerotecnica*, **34**, 204-206 (*Aug.*, 1954) (*In Italian*). Discusses fundamental relations of dynamics with reference to the rocket. (10 *refs.*)

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REVIEWS

Suns, Myths and Men

(By Patrick Moore, F.R.A.S. Published by Frederick Muller, Ltd., London. 192 pp., illustrated. 12s. 6d.)

The first part of this book is devoted to explaining the early myths of astronomy and is worth obtaining for this alone. The author, well known to readers of this Journal, goes back to the misty beginnings of time to describe how early Man viewed the mysteries of the Universe.

Few will fail to be amused at some of the early beliefs—or fail to admire the ingenuity of some of the early observers. Thus, 2000 years ago Eratosthenes calculated the circumference of the Earth, basing his method on the fact that when the Sun is directly overhead in one place, it is some way from the overhead point in another. And so, when the Sun was directly over Syene (Assouan), Eratosthenes measured its altitude at Alexandria and found it to be 7° from the zenith, and as 7° is about one-fiftieth of 360°, the circumference must be fifty times the distance between Alexandria and Syene. No maps were available, of course, to give the distance between these two places and the problem was apparently solved by driving a coach between the two and counting the number of turns made by the wheels. The distance proved to be 5,000 stadia, from which it followed that the Earth's circumference was 250,000 stadia, i.e., 24,850 miles—compared with the true value of 24,900 miles!

The second section describes in the author's easy-to-read style how, through the centuries, man at last realizes that the Earth, far from being the centre of the Universe, is an incredibly small, unimportant speck of dust in the vastness of the cosmos. The slow but sure increase of our knowledge about our neighbouring planets, comets, meteors, distant suns and island universes is told, bringing the picture up to that of the present day.

Of particular interest to space travel enthusiasts is a good answer to that popular question: "How deep is the atmosphere." Recent investigations carried out in Norway have shown that the aurora phenomena experienced at the poles range from altitudes of six or seven hundred miles down to as little as seventy miles. In the words of the book: "Clearly, then, traces of the atmosphere must still exist at these heights. Beyond, the void becomes absolute and we have entered the realm of interplanetary space."

An interesting discourse on "Flying Saucers" will be spoilt for similar enthusiasts by the conclusion that "Either we put down the stories of interplanetary saucers . . . or else we reject modern science in its entirety—not only astronomy, but also chemistry, physics and the rest. It is as simple as that."

It is, of course, not quite as simple as that. Surely, "flying saucers," in the generally accepted sense of the phrase, are a possibility within the bounds of present day scientific thought? One can disbelieve (as the reviewer does) any "flying saucer" story up to the moment referring to a manned or constructed vehicle, and yet believe in their technical feasibility without "rejecting science."

This, however, is only a minor blemish in a book which surveys, in highly readable and exciting manner, past mysteries, present facts and some future expectations.

M. F. ALLWARD.

Physics of the Planet Mars

(By G. de Vaucouleurs. Faber & Faber, Ltd., London. 1954. 365 pp. £2 10s.)

There have been many popular books written on the subject of the planet Mars, but the present volume, translated from the French and brought thoroughly up to date, is of a different nature. It is not a "popular" work in any sense of the term; it is a technical work for the serious student.

The book is divided into five parts. In the first, the Martian atmosphere is discussed in detail; this is followed by a long section on climatology. Part III deals with the polar caps and the water problem in general; Part IV, with the surface features; and Part V with the internal constitution of the globe. Finally, there is a summary of the information, with a long list of references which alone is worth the price of the book; and there are some good photographs.

Dr. de Vaucouleurs confines himself almost entirely to what is definitely known; he speculates but little, and the famous (or infamous) canals are hardly mentioned. In a book of this nature, such caution is obviously wise. The result is that every statement is wholly reliable. There is also much original research in the book, which must be described as a positive mine of information.

The translation is somewhat stilted, and there are cases of words (e.g. "accidental") being wrongly used. This would be a serious flaw in a popular book, but is comparatively unimportant in a technical one; it is always clear what the author means.

In short, this is undoubtedly the most important technical work yet published upon the subject of the Red Planet. It is certain to run to many editions, and no serious student of Mars can afford to be without it.

PATRICK MOORE.

Rocket Exploration of the Upper Atmosphere

(Edited by R. L. F. Boyd and M. J. Seaton in consultation with H. S. W. Massey, F.R.S. Published by Pergamon Press Ltd., London, 1954. 378 pp. 75s. net.)

This book contains the papers read at a Conference held at Oxford in August, 1953, arranged by the Upper Atmosphere Rocket Research Panel of the United States and the Gassiot Committee of the Royal Society of London. The Conference was attended by 79 people, including seven members of the B.I.S. Council; and of the 22 who came from America, most were given transport by the U.S. Office of Naval Research. Delegates stayed appropriately in one of the oldest colleges, Queen's, which was founded in 1340 and therefore dates back nearly as far as the first reported use of rockets by the Chinese.

What the book really amounts to is a detailed summary of all the atmospheric research done with rockets in America since 1946, and of the extent to which it fits in, or fails to do so, with upper atmospheric knowledge obtained on this side of the Atlantic by other methods.

There are 49 papers grouped in seven sections, the first of which, "Rocket Techniques," was dealt with at some length by Mr. J. Humphries in his report of

the Conference published in the *Journal* of the B.I.S. for January, 1954, pp. 32–34.

The second section, "Pressures, Temperatures and Winds," also deals mainly with techniques, and includes the delightful scheme of ejecting from the rocket a deflated nylon balloon which proceeds to blow itself up to 4 ft. diameter, receive and return radio signals from somewhere inside itself, and thus enable air density to be calculated from its rate of descent, which is measured on the Doppler principle. A footnote adds that, since the Conference, one of these spheres has been dropped from 195,000 ft. from an Aerobee rocket.

The third section is on "Composition of the High Atmosphere." It has proved extraordinarily difficult to find out at what height the various atmospheric gases begin to separate out according to their weights. As an example of the ingenuity needed for collecting samples of air at height in an evacuated steel bottle, in one experiment the entry tube was opened by a motor-driven knife and then closed again by being squashed flat with a gunpowder-driven hammer.

Even when the snags of getting genuine high-altitude air into a bottle are overcome, no one seems certain to what extent any of the gases are absorbed on to the walls of the bottle; in fact, so much oxygen disappears that only the changes in proportion of helium, neon and argon are looked for, and even they are suspect. It is interesting that these bottles are sent across the Atlantic to Professor F. A. Paneth, who is the world's expert at analysing tiny quantities of gases.

The bottle experiments seem to show that the gases start separating out above 60 km., but this result is doubted, for one thing because the ozone layer is so hot at 50 km. that the air from that level up to 80 km. should be stirred by convection currents, just as the lower atmosphere is stirred by thermals when the ground gets hot. At greater altitudes, up to 137 km., the mass spectrometer has been tried, but again its results are doubted, mainly because air emanating from the rocket is suspected to have been analysed instead of the true ambient air.

This section concludes with several papers on the ozone layer.

The subjects of the next section, "The Ionosphere, Solar Radiation and Geomagnetic Variations," had already been much investigated before high-altitude rockets came on the scene. In particular, an enormous amount of research on the layers of ionization in the ionosphere has been done by sending up radio pulses into them and analysing the echoes that come down again. A big limitation of this method is that it gives no information on the state of a particular ionospheric layer above the level of maximum ionization from which the radio pulses are reflected. Furthermore, the reflection is more like a refraction, as the radio waves are slowed up during the time they are being bent downwards; this makes for such uncertainty in estimating the height of the reflection that ionospherists have to use the term "equivalent height," which means the height the radio pulse *would* have reached *if* it had gone straight up and down at full speed during the same interval.

These difficulties are overcome in a variety of ingenious ways by rocket-borne instruments, as described in several papers. Of the two most important

ionospheric regions, the *E* layer, at roughly 100 km., is most easily reached and has been most investigated by rockets. The *F* layer is a good deal higher up: it splits during daylight into the F_1 at around 200 km. and the F_2 at about 300 km.

But in one respect the ground radio stations have the advantage, because they can follow the movements of irregularities in ionization which interfere so much with long-distance radio communication on the Earth; in fact, this forms the major part of their work. Rockets simply do not stay aloft long enough to be of much help, except for investigating the momentary condition of one of these irregularities if it has the luck to pass through one.

Rockets have done good work in measuring the extreme ultra-violet and X-rays in the Sun's spectrum and proved that the latter are strong enough to account for the *E* layer.

A section on cosmic ray measurements in rockets, containing only one paper, is succeeded by two on "Laboratory Studies" and "Theoretical Considerations and Suggested Experiments," dealing mainly with what has been done without the help of rockets.

Of special interest is the paper "Consideration of the Results Obtained by Rockets," by Prof. D. R. Bates, of Belfast, in which he points out that rocket research has recently been producing more and more data which conflict with what has previously been deduced from theory. At the Conference no pre-print of this paper was available, and it was not easy to follow the professor as he paced to and fro with an air of being much worried at the discrepancies that had arisen—he is himself one of the world's leading theorists on the subject. Now that it is all set out in print, we can see better what the trouble is about.

The main discrepancies are two. One is that rocket experiments show an incredibly large concentration of ions in the *E* layer and in the upper part of the *D*, a layer which develops below the *E* particularly during magnetic storms. Theoretically those in the *D* layer should disappear too fast to make such a concentration possible, and it is also invalidated by the observed duration of meteor radar echoes. In the *E* layer, rocket data allege that negative ions far outnumber electrons, whereas theory again shows the opposite to be true because, by all known processes, the ions would disappear too quickly. Unless some entirely new and unsuspected process is discovered, Prof. Bates concludes, we must assume the rocket instrumental techniques to be at fault.

The second main discrepancy concerns the temperature of the so-called thermosphere, in which temperature increases with height from 100 km. upwards (it includes most of the ionosphere, which is the cause of the temperature increase). The few rocket ascents into this region give a greater density, and consequently a lower temperature, than expected. This means, among other things, that the *F* region may be much lower than the ground-level radio people thought, and its assumed cause would in that case need modification.

It also means, if one may put it so, that in order to achieve the density they claim to have proved, the rocketeers will have to borrow a lot of air from the "exosphere" higher up; and the scientists who deal with these higher regions cannot spare it because they need it, together with the higher temperatures

which would keep it up at their level, in order to account for their own phenomena. Briefly, they need the density to explain sunlit auroras at 1,100 km., and the temperature to explain the known rate of loss of helium from the top of the atmosphere. However, it is admitted that the temperature required to get rid of the helium, 1,500° K., need not be present all the time; it would be enough if some intermittent phenomenon only pushed the temperature above that figure occasionally.

This chapter by Prof. Bates is rather fascinating as showing what a state of flux the whole subject of the higher atmosphere has got into, though it may be hard going for anyone not too familiar with the relevant physics.

Finally there are two papers by S. F. Singer, an American member of the B.I.S. who recently spent some time in England. One of these, explaining the need for long-continued observations from outside the ionosphere at some 400 km. altitude, comes to the following pleasing conclusion, cautiously expressed so as not to startle the unconverted:—

"It would seem that a satellite would be an ideal vehicle for certain astrophysical observations, particularly those of the solar radiations. It would seem that the scientific benefits derivable from these observations would justify the building of a small satellite vehicle, the cost of which might be quite reasonable compared with the cost of using some 100 high altitude rockets (and their necessary instrumentations) for a similar purpose."

A. E. SLATER.

To Other Worlds

(By Werner Buedeler, translated by A. L. Helm. Burke Publishing Co., Ltd., London. 224 pp., 24 pages of photographs, 50 line drawings. 18s.)

Originally published in Germany in 1952 as *Telescopes, Rockets, Stars*, this is a new edition brought up to date by the author before translation. It has been written in a simple, friendly manner, and the translator has done justice to the enthusiasm of his author. At the same time it is felt that the new title is not fully justified. The complete section on rockets and the *modus operandi* of space-flight occupies only 50 pages. The remainder of the book and three-quarters of the photographs follow the progress of man in his attempts to see and understand the universe around him, and reviews present knowledge of our solar and stellar neighbours. The book as a whole traces a philosophical continuity between astronomer and astronaut.

The first half of the book is quite pleasingly presented, and shows no chink in the author–translator team's armour. Starting before Galileo, and before telescopes, the efforts of man to find order in the apparent confusion of the heavens are traced up to date. The work of Hale receives considerable attention and with it the American story of astronomy and cosmology. In turn, the historical and mechanical problems of the 40-in. lens at Yerkes observatory, then the 60- and 100-in. reflectors at Mount Wilson, and finally the 200-in. Hale reflector at Palomar are told in some detail.

"Rockets," which is the sub-title of the second part of the book, gives the reader some idea of the speed with which he is whisked through the subject.

After briefly reporting upon the doings of the Douglas Skyrocket and the V2 and WAC Corporal, the existing knowledge of the atmosphere is described. There follows a short review of solid and liquid "fuel" rockets, then the journey of a V2 from White Sands upon a research flight is told. Within the final 20 pages the reader is placed on nodding acquaintance with much of both the publicized plans of campaign of Braun, Ross and others, and also the jargon of rocket vehicle dynamics. So we meet such terms as exhaust and final velocities, mass ratios, step-rockets, artificial satellites and the Roche limit, gravity, free fall, cosmic radiation, and not least, atomic motors.

The last part of the book, "Stars," begins by asking, "What is life?" Carbon chemistry is thought about, and then the possibility of life on other worlds. In spite of the rather unhappy selection of environments within the solar system, which are described in some detail, the book finishes in high optimism upon thoughts of other planetary systems and happier climates.

To Other Worlds is not a textbook and numerical accuracy is not expected to be on such a high level. On the other hand, clarity of expression and accuracy of definition are, in the opinion of the reviewer, of greater importance. It is unfortunate that just a few times in the text such errors have crept in. An example of a free fall is given as "a crashing aircraft." It is stated that g is equal to feet per second. There is a paragraph wherein the relationship between exhaust and final vehicle velocities is not clearly put. The paragraphs under the heading "Reaction Principle" would not help to convert the rockets-won't-work-in-space type of opposition. Numerically, g falls to half sea-level at 1,660 miles up, the diameter of the solar system is 7 not 72 thousand million miles, and the cost to the Moon at 2d. a mile is more nearly £2,000. The line drawings are good in intention but often not in execution, and occasionally the titling is difficult to read. Finally, there is a photographic reproduction which is indexed as "Chinese Atomic Rocket" which might not please Professor Tsien of Cal. Tech., though the titling does contain the only example of the word propellent in the book.

D. S. CARTON.

CORRESPONDENCE

Lunar Accommodation

SIR,

I should like to comment on two letters in the May 1954 *Journal*.

Mr. Camp's suggestion is sound, but one is faced with constructional difficulties. It would be impossible to place any but the smallest of point loads on the sheeting, so that a man could not stand on it—unless it was made strong enough for the purpose, which would seriously reduce the scheme's economy—and extreme care would have to be taken in distributing the covering rubble. Thus it can be seen that the size of the structure is limited by the size of the gantry or boom used to spread the rubble. In spite of this, the idea appears to have possibilities. Incidentally, Mr. Camp says "the sheeting could be made slightly elastic in order to reduce any tensile stresses resulting from slight maladjustment of the internal air volume" (I presume he means pressure).

This statement is either erroneous or unfortunately phrased. Since in an elastic body stress is proportional to strain, the stretching of the sheet would not of itself relieve the stress; however, in doing so it would increase the enclosed volume, hence reducing the pressure, which is, I think, what was meant. It is to be hoped that the air pressure will be controlled very closely, since otherwise a sheet of material of low enough modulus of elasticity may not be available to prevent rupture.

Regarding Mr. Neumark's letter, he appears to be thinking of my suggestions in application to his own ideas expressed in his first letter (*J.B.I.S.*, **12** (3), **146**, May, **1953**); however, my paper was written before this letter appeared and thus some confusion is occasioned by comparing the two conceptions when they have differing assumptions. To proceed paragraph by paragraph:—

(1) This is one statement that confuses me. To my mind, the inflated dome is essentially a surface construction, for which there is no necessity in sealed underground workings. I presume that the implication is that the subway, not the airlock, is the "unnecessary complication"! This is probably true—my own contention was that there would be little difficulty in fitting airlocks to the sides of the dome.

(2) I agree with this statement, with the reservations made above. The idea of utilizing lunar dust for insulation is one I have encountered elsewhere, though it never occurred to me. Nevertheless, the presence of lunar dust in quantities sufficient for the purpose is not really proven, and I feel it would be safer to rely on a highly reflective surface to the dome. The manufacturers of aluminium paint claim a reflectivity of 75 per cent. for their product, and whilst this may be sufficient, it can probably be bettered.

(3) When I spoke of the complete sphere I was thinking of one sunk in the ground and filled with rubble to ground level to provide a floor. This was undesirable on account of the difference of temperature to which the two halves of the sphere would be subjected, and the weight of the lower half to be transported from Earth would not give any extra pressurized space. Shortly after writing the letter, though, I devised a structure composed of a spherical shell resting on the ground, with a central column inside to carry the floors and to transmit vertical loads to the ground. The design requires more detailed investigation than it has yet received, but I hope to present a detailed layout at some later date.

(4) My assumptions were based on an open-bottomed hemisphere, anchored at the perimeter and sealed by air pressure on a loose flap or continuous valve. Assuming an unbroken, closed hemisphere, as Mr. Neumark says, it will tend to form a sphere, which tendency can be restrained by H.D. bolts as before, or by adopting Mr. Neumark's "suitable envelope design," an idea also expressed by Mr. R. A. Smith at Manchester last February. To resist all the forces acting on the bottom, viz., a uniform pressure from the enclosed air over its whole surface, and an opposite, quantitively equal peripheral force from the skin of the dome, would require (using C. C. Pounder's formula) a solid steel plate, assuming uniform thickness for convenience, of 2·84 in. thick in a 10-ft. radius dome (10 p.s.i. air pressure). This would weigh about 16 tons. Uniform thickness is not efficient, so I roughed out a method of stiffening the bottom with

steel ribs, with the assistance of the procedures outlined by Pounder. The requirement, very roughly, was for a grating of 20 in. $\times$ $\frac{1}{4}$ in. ribs, 1 ft. apart over the whole area of the bottom, weighing around 4·7 tons. This is more reasonable, but even counting on a more economic arrangement and shape of ribs (which can be effected for sure), when one considers the smallness of the dome, and the amount of work entailed in welding up the ribs, this scheme seems most uneconomic.

(5) I had considered internal partitions for large domes only, and apart from the normal requirements of separate rooms, they would be used to carry the upper floors—a procedure both economic and practical in view of the lower loadings imposed by lunar gravity.

(6) Plastic sealing films would definitely be better than cement—my enthusiasm to find employment for lunar-made cement led me to ignore its inefficiency for the job, comparatively speaking, in the face of other substances now in existence.

(7) This double dome is, I agree, a good idea, and would require little or no more material than the single dome, since the thicknesses would be less, and bear the same proportion to each other as the two air pressures, i.e., if the inter-dome pressure was half the inner dome pressure, the shells would each be approximately half the thickness of a single dome shell of the same radius. In addition to providing anti-puncture protection, the outer dome would also act as a heat shield.

P. L. SOWERBY.

West Didsbury, Manchester.

Astronautical Fallacies

SIR,

Mr. Arthur C. Clarke ("Astronautical Fallacies," *J.B.I.S.*, Nov., 1954) states that it is "hard to explain that one can be completely weightless while still in a gravitational field."

I suggest that the difficulty can be overcome if the term "reactionless" is adopted in place of the term "weightless." Strictly speaking, a body must possess weight in a gravitational field, its weight being the force exerted on it by the field. The important thing when a body is moving freely under the action of gravity is that there is no reaction to its weight. The so-called "weightless" state is, in reality, a "reactionless" state.

Consider, by way of example, the condition of an occupant of a space station in a circular orbit around the Earth just above the atmosphere. His weight is almost as great as it would be on the Earth's surface, but as he and the station are moving freely in the Earth's gravitational field he experiences no reaction to his weight. The accepted solution to the problem is to spin the station about its own axis, the centripetal force exerted on the occupant by the station then providing him with the equivalent of the reaction to his weight which the ground exerts on him when on *terra firma*.

S. W. GREENWOOD.

Weston-super-Mare, Somerset.

Some Remarks on Strughold's Ideas

SIR,

Since the above article was written, a new suggestion to account for the dark areas on Mars has been put forward by Dean B. McLaughlin, of the University of Michigan Observatory, in *"The Observatory"* for August, 1954 (Vol. 74, No. 881, "Wind Patterns and Volcanoes on Mars." pages 167–8). Struck by the number of shapes which repeat themselves round the Martian globe, he suggests that they consist of mineral matter drifted by a system of winds resembling the trade winds on the Earth. Formations like the well-known Syrtis Major, and its smaller copy the Margaritifer Sinus, which have the shape of a twisted wedge, he would explain as formed from drifts originating at the point of each wedge, and the only likely source of such matter would be volcanoes.

Meteorologically, his wind system seems plausible, but in turbulent winds matter from a point source spreads into the shape of a parabola with ill-defined boundaries, not a sharply bounded wedge like the Martian formations. If the winds are not turbulent, the matter would drift away in a straight line—a convenient explanation of the "canals." But to produce an evenly-spread wedge-shaped deposit with a sharp edge, the wind would have to deviate in such a way as to blow with equal frequency in every direction between two sharply defined limits; otherwise any specially favoured directions would each produce a darker spoke-like line of deposit radiating from the point source. Some of the late Percival Lowell's drawings actually show such lines, which of course he recognized as canals penetrating the dark areas; see especially the Syrtis Major in the left-hand drawing on page 136 of his *Mars as the Abode of Life* (The Macmillan Company, New York, 1909).

McLaughlin's hypothesis would explain why the dark areas are warmer than the "deserts," instead of cooler, as should be the case with vegetation. Also, it gets round Dr. E. J. Öpik's argument (*Irish Astronomical Journal*, Vol. 1, No. 2, June, 1950, pages 45–46) that in the absence of vegetation the dark areas would have been long ago covered by yellow dust blown from the deserts. The seasonal changes of colour would still need explaining, but McLaughlin promises a more detailed account of his ideas later in the *Publications of the Astronomical Society of the Pacific*. Since he has already said that the winds will be strongest in the southern summer, when Mars is at perihelion, one may guess his explanation to be that, at other seasons, desert dust drifts over the green areas and turns them brown. The same explanation of colour changes would hold equally well, of course, even if the dark areas really are vegetation.

The need for a refined spectroscopic survey of Mars seems more urgent than ever.

A final point: Strughold, on p. 12 of his book, stresses the need for water "as a prerequisite for active life." However, it should not be supposed that all the water needed has to be already present in the environment. Recent work on certain desert animals has shown that they give out more water than they take in, so the presumption is that they manufacture some of it chemically within their bodies.

A. E. SLATER.

Dunstable, Beds.

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